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WIND-TUNNEL INVESTIGATION OF ALTERNATIVE PROPELLERS OPERATING BEHIND DEFLECTED WING FLAPS FOR THE XB-36 AIRPLANE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

WIND-TUNNEL INVESTIGATION OF ALTERNATIVE PROPELLERS OPERATING BEHIND DEFLECTED WING FLAPS FOR THE XB-36 AIRPLANE

By Emanuel Boxer

SUMMARY

Tests have been conducted in the Langley propeller-research tunnel to determine the aerodynamic characteristics of two pusher propellers of identical plan form, but different airfoil sections operating behind a slotted flap. The tests were made upon a wing-flap-nacelle combination simulating the arrangement at the center nacelle of the XB-36 airplane. Conditions at the inboard nacelle were simulated for several tests by adding a model of the landing gear.

Tests were made over the range of blade angles and flap deflections necessary to cover all flight conditions of the subject airplane.

The propellers, one embodying NACA 16-series sections, the other Clark Y, exhibited very similar efficiencies within experimental error at low tip speeds for all flap deflections. The peak efficiency of both propellers was reduced 2.5 and 6 percent for 20° and 40° flap angles, respectively. At the take-off power coefficient of 0.055 and estimated take-off flap angle of 20°, the efficiency loss caused by the flap is slight.

Extension of the landing gear decreased the maximum and take-off efficiencies inappreciably for most conditions.

Compressibility effects at a tip Mach number of 0.94 caused a 4 percent reduction in peak efficiency for the 16-series propeller when operating at a blade angle of 10°.

For the same condition the Clark Y propeller experienced a 2 percent increase in peak efficiency.

INTRODUCTION

An investigation of the effects of deflected wing flaps upon the propulsive efficiency of propellers for the XB-36 airplane has been made in the Langley propeller-research tunnel at the request of the Air Technical Service Command, Army Air Forces.

The Consolidated-Vultee XB-36 airplane is dependent upon the use of wing flaps to take off in the specified distance. The effect of the flap wake upon the pusher propellers was unknown, but a serious impairment of efficiency was implied by the results of several British tests. Therefore, a model was built simulating the center nacelle of the XB-36 airplane which in the interest of obtaining results as rapidly as possible was provided with an available low activity-factor propeller with Clark Y section. Unpublished results obtained with this configuration proved the feasibility of take-off with the arrangement of the XB-36 airplane propulsive unit; however, the correct value of propeller thrust necessary to compute the take-off distance was not obtained. The efficiency at any given forward speed varied as much as 10 percent depending upon the activity-factor correction used. Therefore, an additional series of tests was made using a model of the XB-36 propeller (Curtiss 1129-24 embodying NACA 16-series sections). Preliminary tests of this propeller indicated unsatisfactorily low efficiencies with deflected flaps which at that time were thought to be due to the adverse effects of oscillating flow upon the 16-series section. To determine the effect of blade section, another propeller of the same plan form but embodying Clark Y sections was built and tested. The large losses noted in the preliminary tests were subsequently traced to variations in the drag of the configuration with propeller removed.

Tests were made over the range of blade angle and flap deflection to cover all flight conditions of the XB-36 airplane. Although neither full-scale Reynolds number nor blade wake-passage frequency could be duplicated for these tests, the distribution of Mach

number along the blade was obtained at a blade angle lower than that for take-off to determine the Mach number effects upon the propulsive efficiency.

APPARATUS AND METHODS

The model consisted of a constant-chord wing with nacelle and flap simulating the arrangement at the center nacelle of the XB-36 airplane. (See figs. 1 and 2.) The scale of the model (4/19) was selected on a basis of the propeller available for the preliminary tests. A wing span of 15 feet was selected to prevent tip effects from influencing the results. The single-slotted flap was used throughout the present series of tests because the optimum design of a double-slotted flap had not yet been obtained. The extended landing gear simulating conditions at the inboard nacelle was used for several of the tests. Because of uncertainty of the final design, the nacelle nose was faired to meet the wing, omitting the air inlet in the nose of the nacelle. The exit-air slot at the juncture of the nacelle and spinner was faired over. Proposed propeller cuffs were not employed.

The 4-foot-diameter model propellers, the blade-form curves of which are given in figure 3, are of identical plan form (fig. 4) but differ in airfoil section and pitch distribution. The Curtiss 1129 propeller was designed embodying NACA 16-series sections. The propeller incorporating Clark Y sections was built with a slight modification of pitch distribution to allow for the difference in airfoil characteristics. The activity factor for both blades is 121.

The proposed two-speed propeller drive of the original power-plant design has been abandoned for structural reasons in favor of a single-speed reduction. The new compromise gear ratio is now 0.381 which at the take-off engine rating yields a power coefficient of 0.055. The corresponding no-flap take-off advance ratio is reduced to 0.59.

The thrust of the installation was determined from the tunnel balance system. To minimize variations of basic (propeller removed) drag resulting from changes in wing surface conditions, a strip of linen tape was doped

to the wing surface approximately 5 percent of the chord from the leading edge. The propeller torque was measured by a spring-type autosyn-indicating dynamometer.

The testing procedure followed for the present tests was to operate the propeller at a constant speed predetermined for each blade angle, while increasing the tunnel velocity from 30 to 100 miles per hour. The rotational speed was selected so that the propeller would operate near zero thrust at 100 miles per hour. In order to obtain sufficient test points at blade angles greater than 25°, the test procedure was as follows: first, the rotational speed was set at the maximum value obtainable at a low tunnel airspeed and the tunnel airspeed was increased to 100 miles per hour; and second, at a tunnel airspeed of 100 miles per hour the rotational speed was reduced until zero thrust was obtained.

Tests were made at 0° wing angle of attack for flap angles of 0°, 10°, 20°, 30°, and 40° and for blade angles varying from 12.5° to 25° in 2.5° increments. Tests were also made of each propeller with wing flap neutral for 5° blade-angle increments from 25° to 50°. Additional tests were made with flap neutral and at a blade angle of 10° in which the propeller rotational tip speed was varied from 413 to 1040 feet per second. At the latter speed the Mach number distribution along the blade closely approximated that of the full-scale propeller at take-off, although power limitation prevented duplication of the take-off blade angle.

SYMBOLS

D propeller diameter, feet

S wing area, square feet

V velocity of air stream, feet per second

ρ density of air, slugs per cubic foot

q dynamic pressure, pounds per square foot $\left(\frac{\rho V^2}{2}\right)$

δ_f flap angle, degrees

$\beta_{0.75R}$ blade angle at the 0.75 radius, degrees

n propeller rotational speed, rps

C_D drag coefficient $\left(\frac{\text{Drag}}{qS}\right)$

C_L lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$

J advance ratio $\left(\frac{V}{nD}\right)$

C_P power coefficient $\left(\frac{\text{Power}}{\rho n^3 D^5}\right)$

C_T thrust coefficient $\frac{T_e}{\rho n^2 D^4}$ or $\left(C_{D_c} - C_{D_p}\right) \frac{SJ^2}{2D^2}$

T_e effective thrust, obtained by adding the drag of the model with propeller removed to the resultant measured horizontal force with propeller operating at the same stream dynamic pressure and model lift coefficient

η propulsive efficiency $\left(\frac{JC_T}{C_P}\right)$

Subscripts:

c denotes propeller removed

p denotes propeller operating

RESULTS AND DISCUSSION

The results of the present investigation are presented in the usual propeller coefficient form of C_T, C_p, and η plotted against the advance ratio J. Results of tests simulating the center nacelle are presented in figures 5 to 8, the landing gear extended or inboard nacelle results in figures 9 and 10.

An indication of the accuracy of the data is shown by the test points in figure 6(a). The curves were faired and cross faired as a family for any one configuration. The necessity for so doing is apparent from the scatter

of the force measurements shown in figure 11. The propeller-removed drag coefficient used to compute the thrust is obtained from the wing polar curve at the value of the propeller operating C_L. However, the large lift force fluctuations dictate the use of a faired C_L variation with advance ratio to reduce scatter of C_T test points. Thus in figure 11 the solid curve is the original fairing used to compute the test results for the 20° blade angle of figure 6(a). The dashed curve represents the change in fairing necessary to attain the cross faired C_T curve. The maximum divergance between the two curves occurs at a J of approximately 0.8, with a corresponding increase in C_{D_c} of 0.0020 or roughly 3 percent in efficiency.

The results of propeller tests with flap neutral (figs. 5 and 7) may be used directly to determine the efficiencies for various flight conditions. Except at extremely high blade angles, the maximum efficiencies of both propellers can be regarded as equal. In general, the results of the low-speed tests indicate that the differences in efficiencies between the Clark Y and 16-series propellers are within experimental error.

Effect of flaps.- A comparison of the peak efficiency envelopes for the retracted landing-gear condition are shown in figure 12. At the no-flap take-off advance ratio of 0.59, the peak efficiency of 79 percent was reduced 2.5 and 6 percent as the flap was deflected to 20° and 40°, respectively.

For the take-off run computation of the XB-36, the only valid comparison of effects of flap deflection upon efficiency or thrust is one at constant power coefficient. Results obtained by cross-fairing at $C_p = 0.055$ are shown in figure 13. For a 20° flap angle the efficiencies of both propellers were only slightly reduced throughout most of the range of J from 0 to 0.59.

The maximum efficiency (fig. 14) is only slightly affected by the landing gear. The added decrement of efficiency caused by flap deflection is of the same magnitude as with landing-gear retracted. Several smoke tests made of the flow past the landing wheel indicated that although somewhat deflected by the flap, a portion of the wheel wake still entered the propeller disk even at the maximum flap angle.

The effects of flap deflection at constant power coefficient with landing gear extended are shown in figure 15. The decrease in efficiency is approximately 2 percent for a 20° deflection and 5 percent for a 40° deflection.

The results of the present investigation agree substantially with those of the preliminary unpublished data except at small flap angles with landing gear extended. The previously obtained decrease of 4 to 5 percent in efficiency for flap angles of 20° or less has not been obtained.

Effect of tip Mach number.- The effects of compressibility upon each propeller are shown in figure 16. The increase in thrust and power absorption with increasing tip speed is as anticipated by airfoil theory and verified by previous investigation. (See reference 1.)

The peak efficiency of the propeller with Clark Y sections increased 2 percent and the peak efficiency of the propeller with 16-series sections decreased 4 percent as the tip Mach number was increased from 0.40 to 0.94. One would expect the propeller embodying NACA 16-series sections to possess a higher critical tip Mach number than the Clark Y. This is true at the design condition. However, calculations indicate that at peak efficiency for the low blade angle of 10°, the tip sections are operating near zero C_L indicating large negative peak pressures for the well-cambered 16-series sections and a consequent loss of elemental thrust from early shock. Figure 17 presents an analytical check of these results based on data of reference 2. The efficiency is shown to decrease with Mach number although not as rapidly as is indicated experimentally. However, at the take-off blade angle and flap deflection the blade will be more heavily loaded and the efficiency decrements should be smaller. The Clark Y section does not experience large negative peak pressure near zero lift and, therefore, the propeller exhibits an efficiency gain due to the favorable compressibility effects.

SUMMARY OF RESULTS

The results of this investigation are summarized below:

1. Low-speed test data indicate that except at extremely high blade angles the maximum efficiencies of both propellers can be regarded as equal.

2. At the take-off advance ratio, the peak efficiency of both propellers at the center nacelle was reduced 2.5 and 6 percent for 20° and 40° flap angles, respectively.

3. At the take-off power coefficient of 0.055 and estimated take-off flap angle of 20°, the apparent efficiency loss is within experimental error.

4. Extension of the landing gear decreased the maximum and take-off efficiencies of both propellers slightly for most conditions.

5. At a blade angle lower than that for take-off the compressibility effects at the tip Mach number of 0.94 caused a 4 percent reduction in peak efficiency for the 16-series propellers and an increase of 2 percent for the Clark Y.

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REFERENCES

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2. Stack, John: Tests of Airfoils Designed to Delay the Compressibility Burble. NACA Rep. No. 763, 1943.

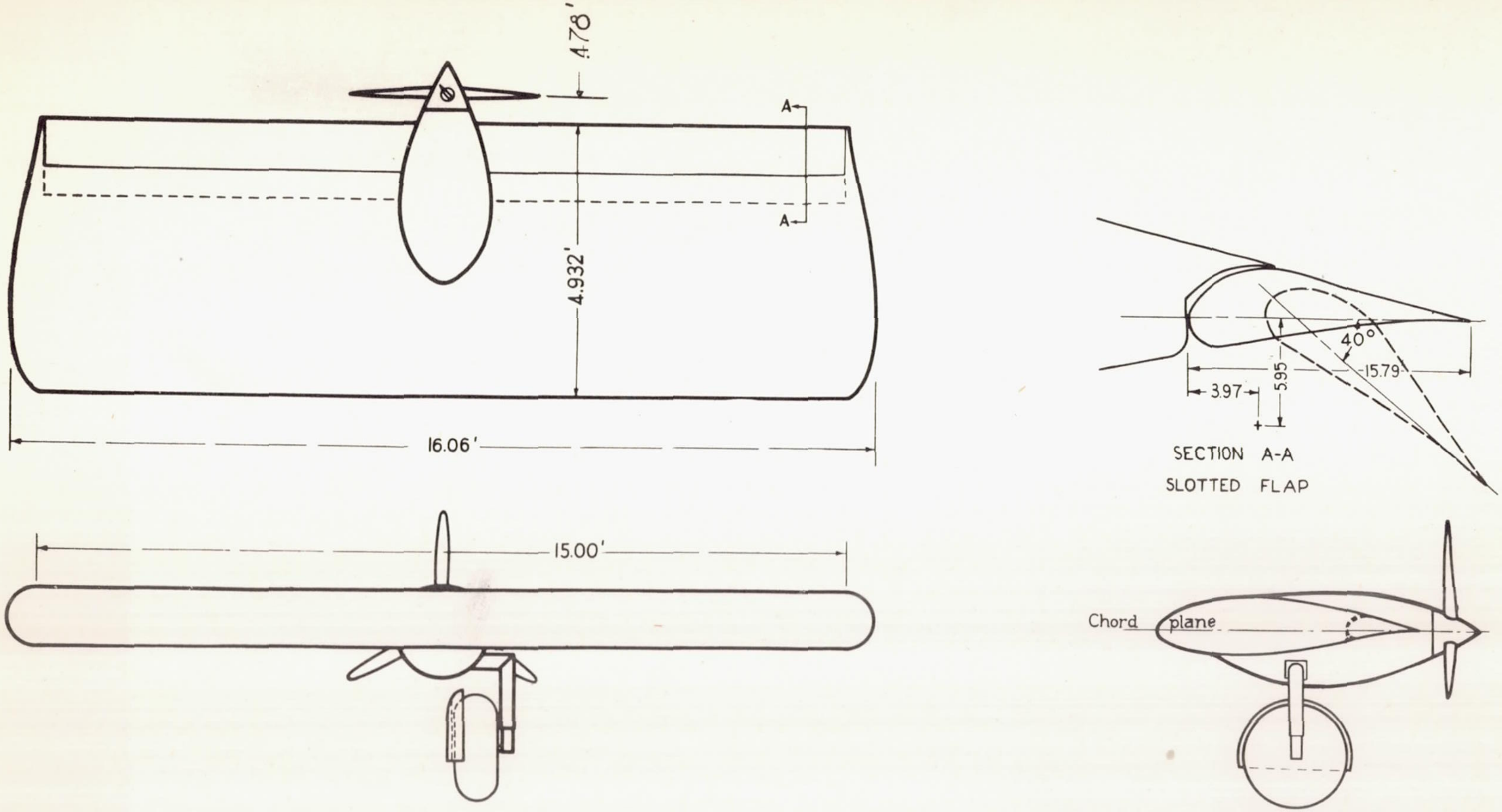

Figure 1.- General arrangement of the XB-36 propeller test model.

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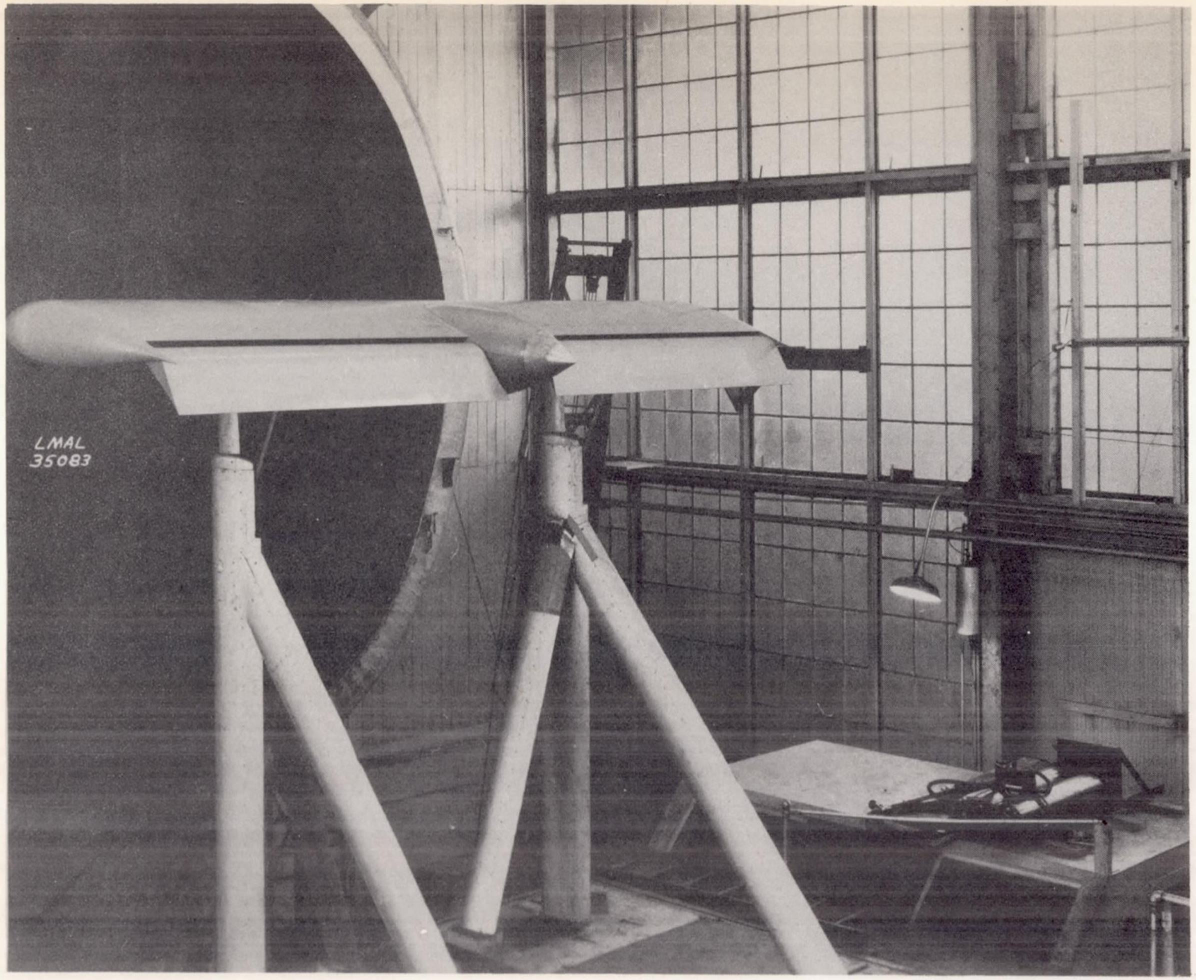
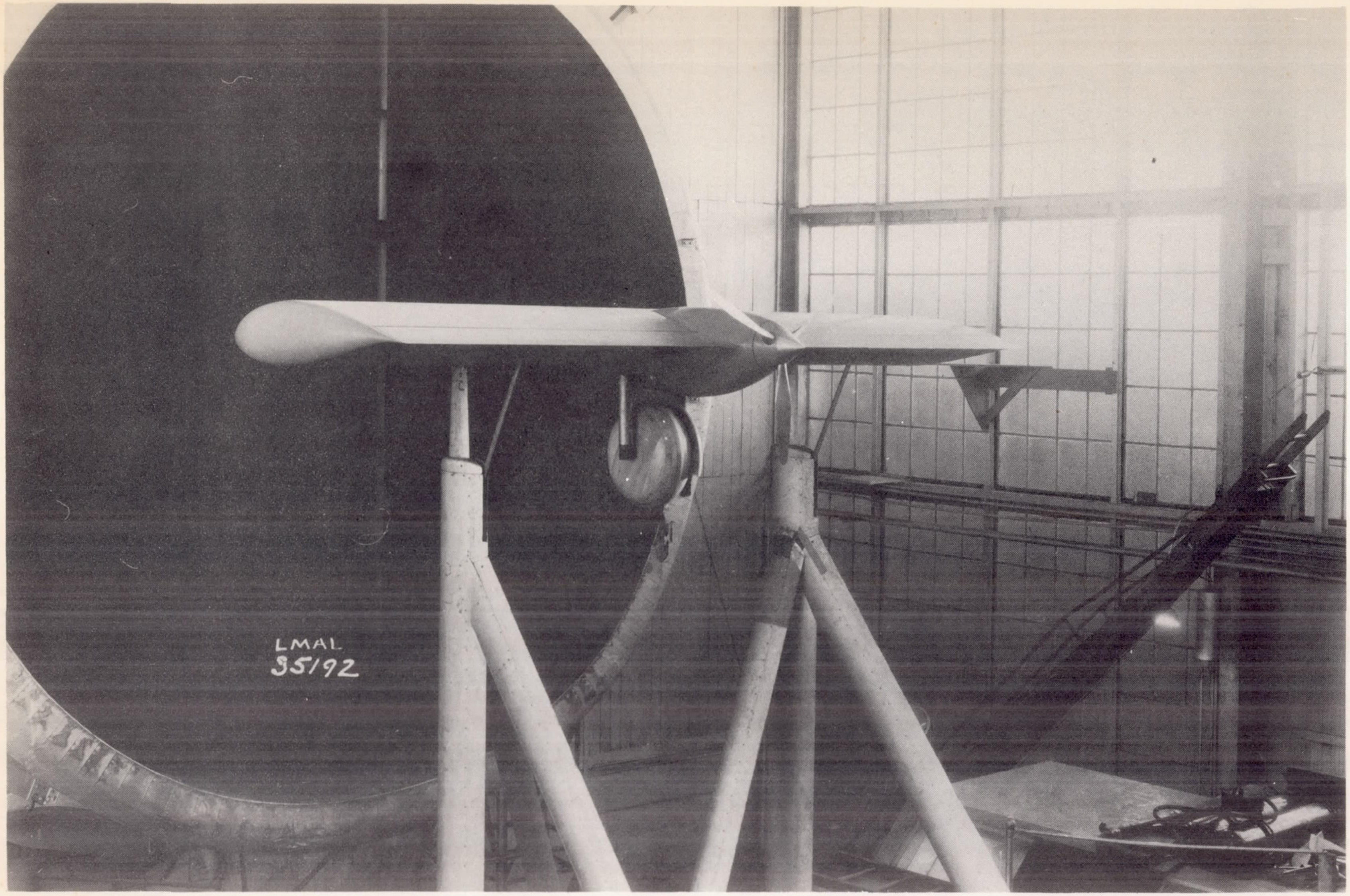


(a) Model prepared for basic drag tests. $\delta_f = 40^\circ$, landing gear retracted.

Figure 2.- Test setup.



(b) $\delta_f = 0^\circ$, landing gear extended.

Figure 2.- Concluded.

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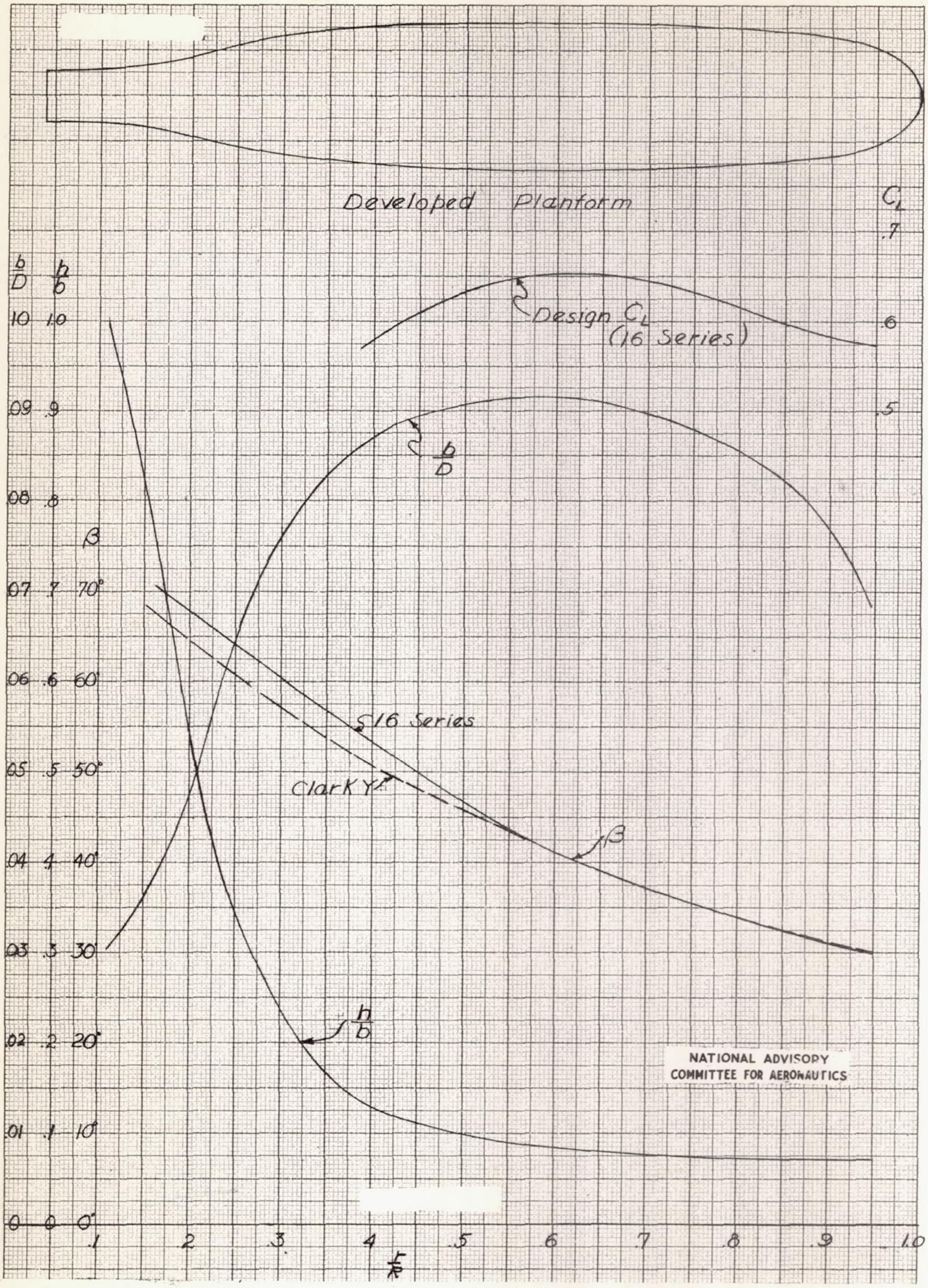

Figure 3.- Blade-form curves for the 1129-24 propeller (R, radius to the tip; D, diameter; b, section chord; h, section thickness; r, station radius; β, section blade angle).

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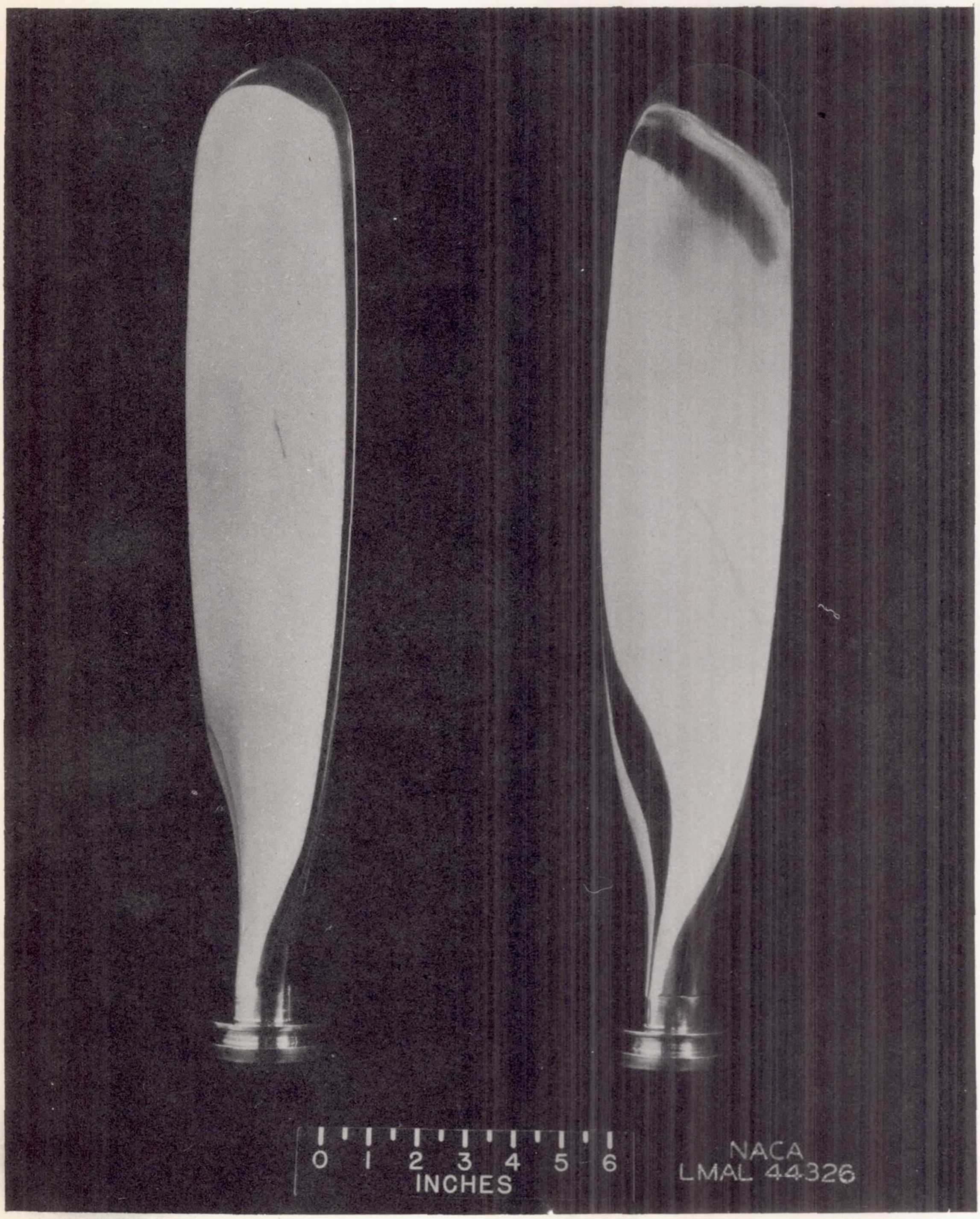

Figure 4.- View of 1129-24 propeller blades, Clark Y left, 16-series right.

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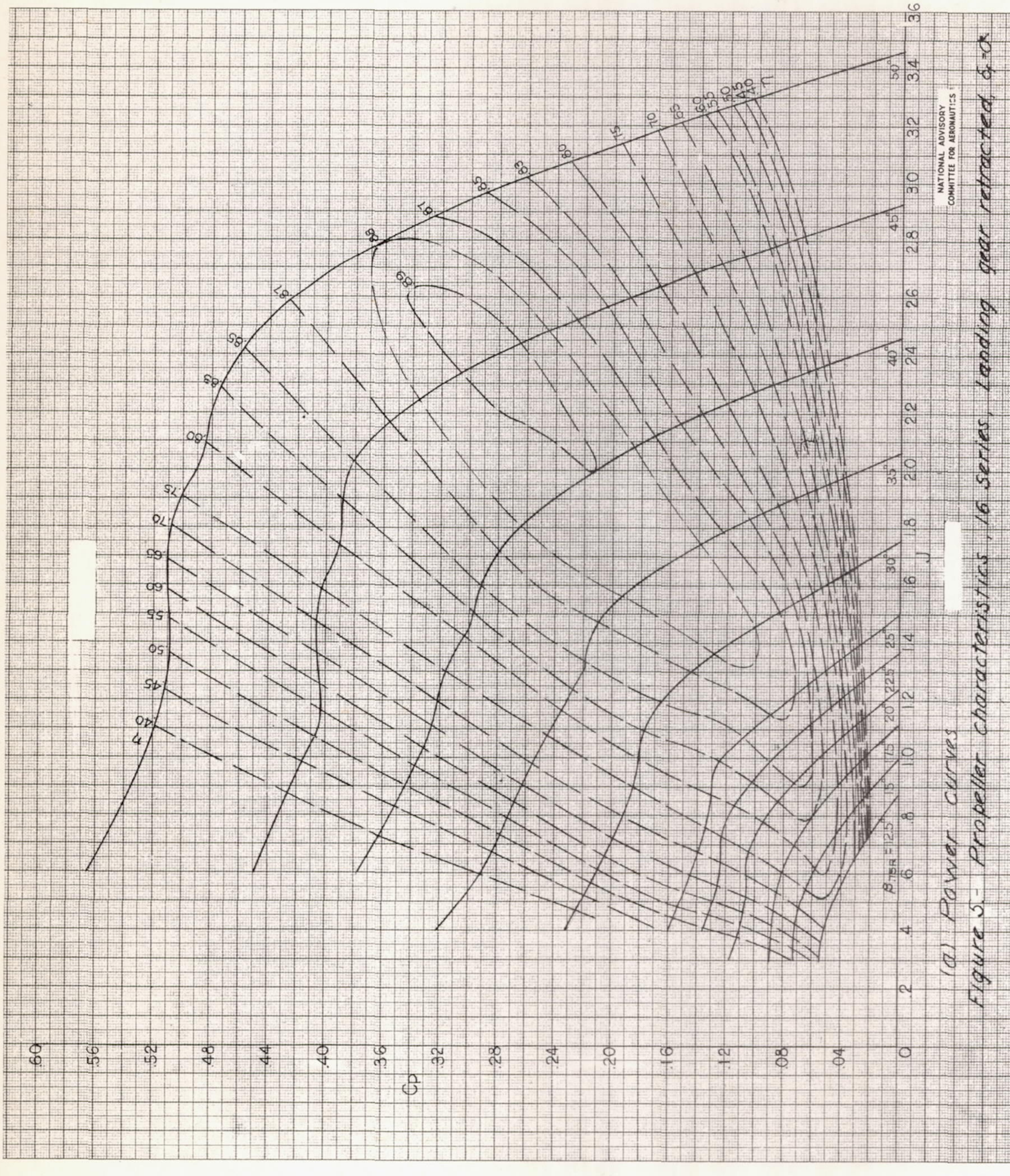
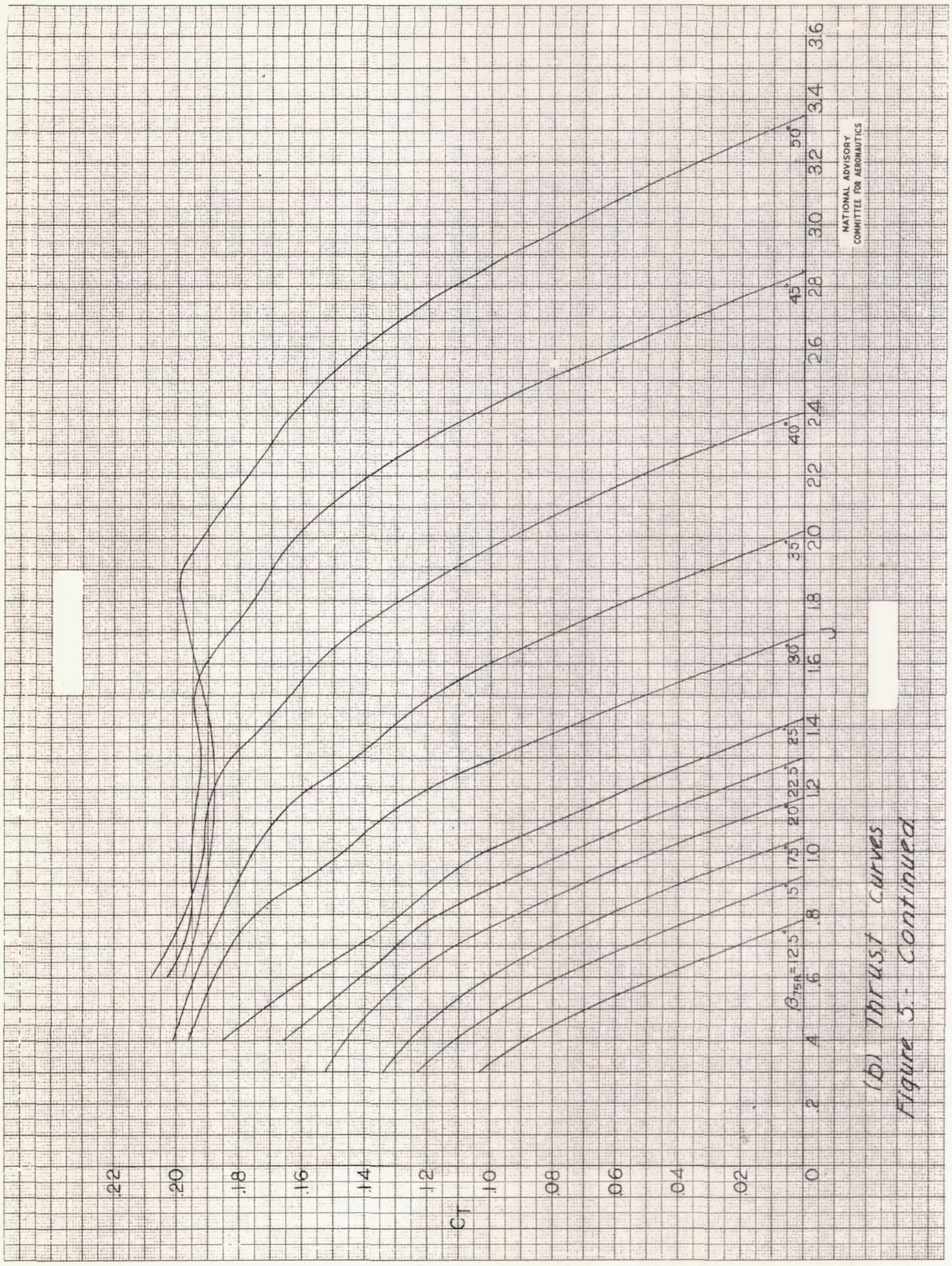


(a) Power curves

Figure 5.- Propeller characteristics, 16 series, landing gear retracted, $\delta_f = 0°$

L-533



(b) Thrust curves

Figure 5.- Continued

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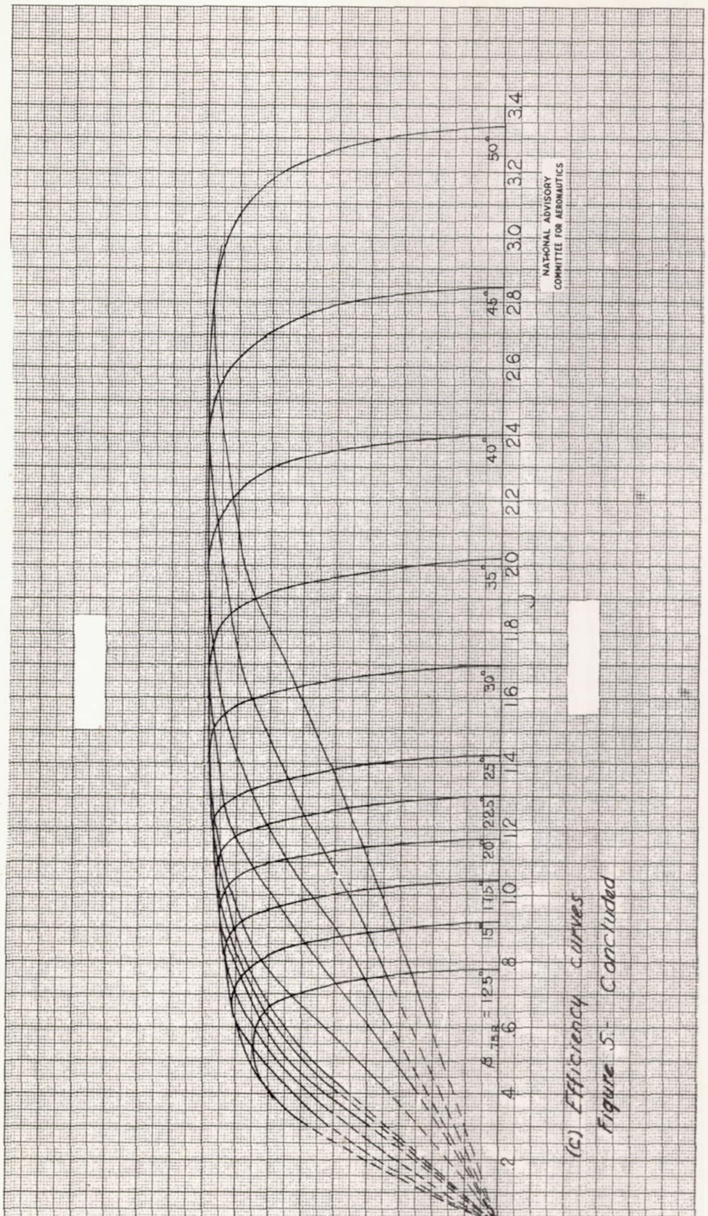
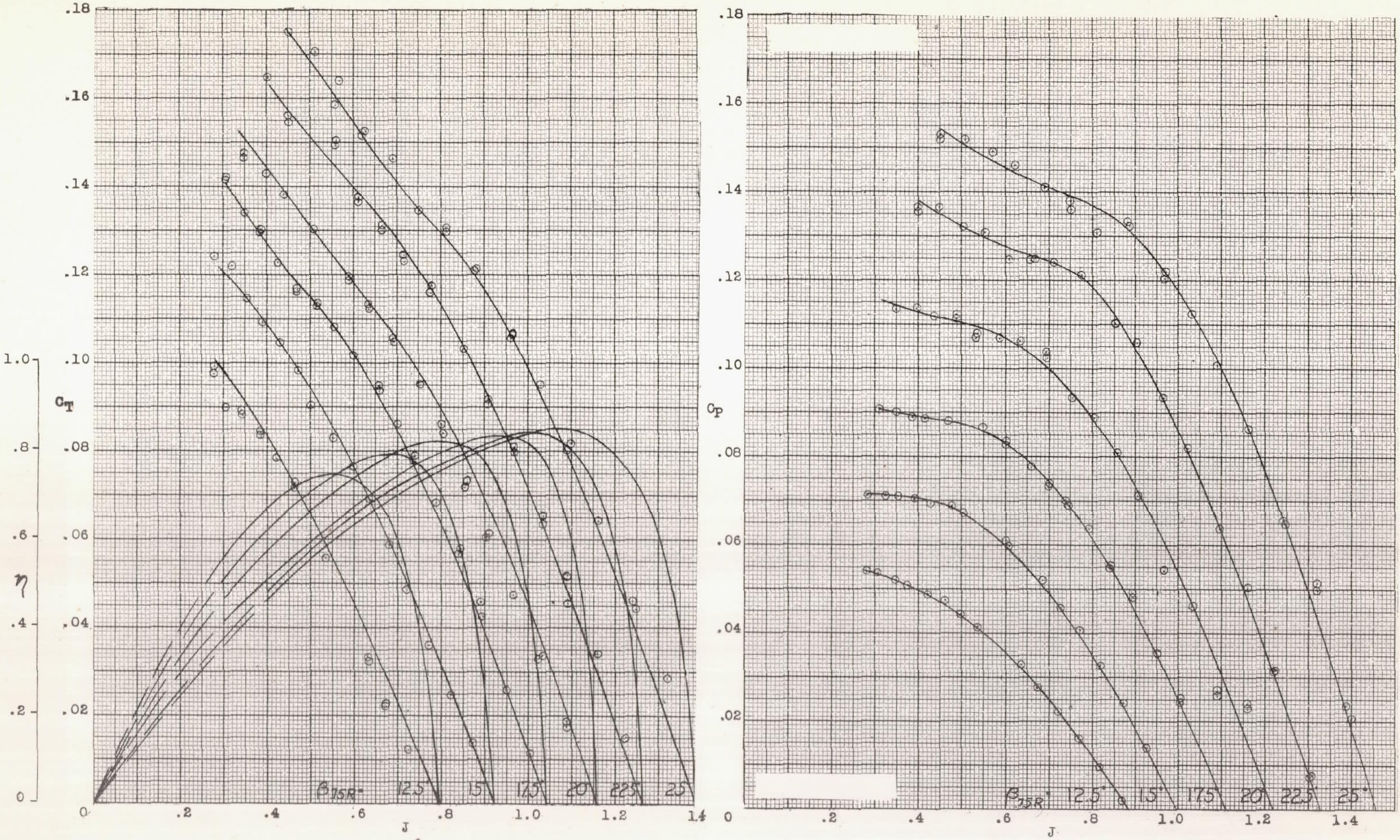


(c) Efficiency curves

Figure 5.- Concluded



(a) $\delta_f = 10^\circ$

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Figure 6.- Propeller characteristics, 16-series, landing gear, gear retracted.

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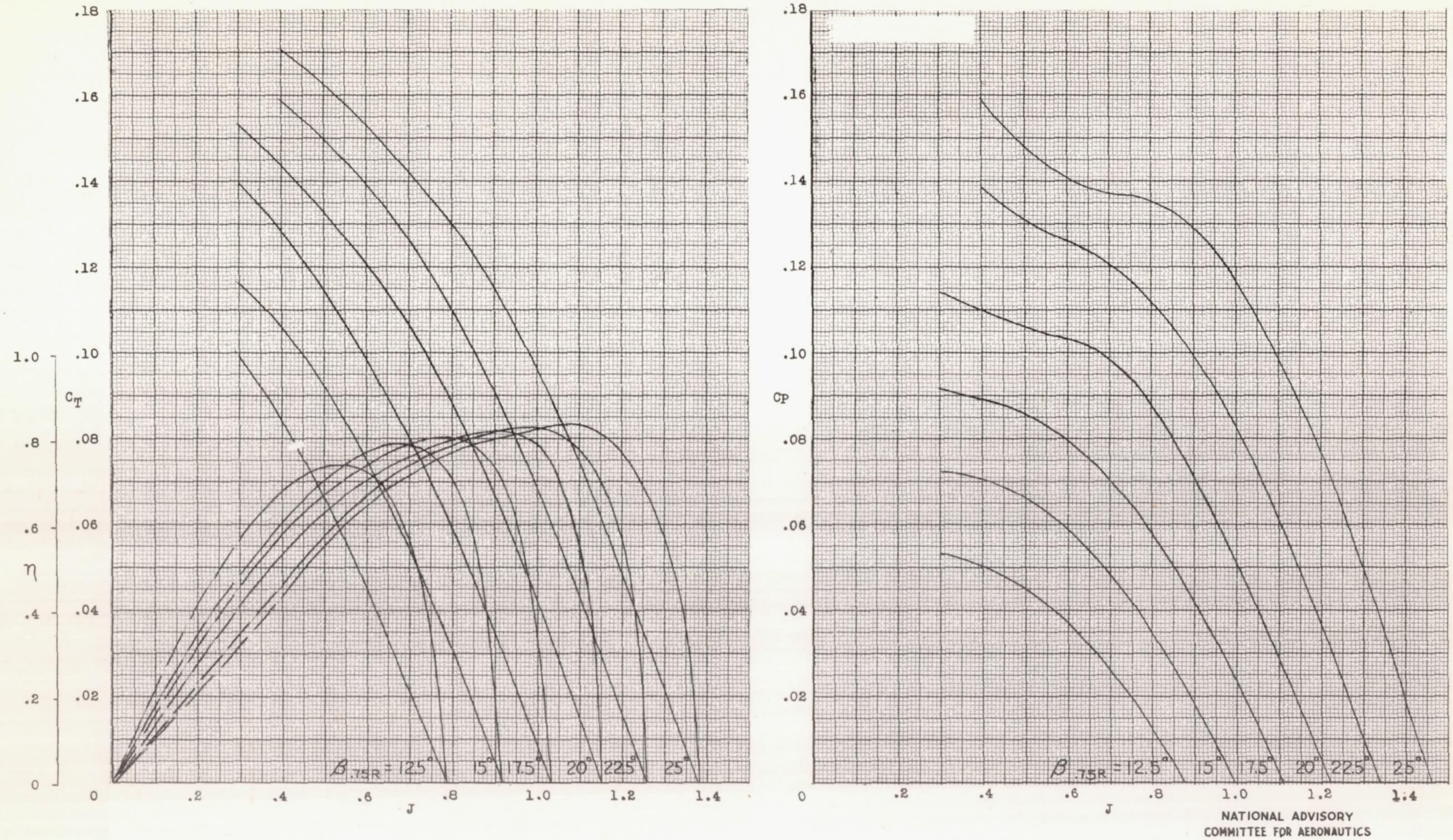
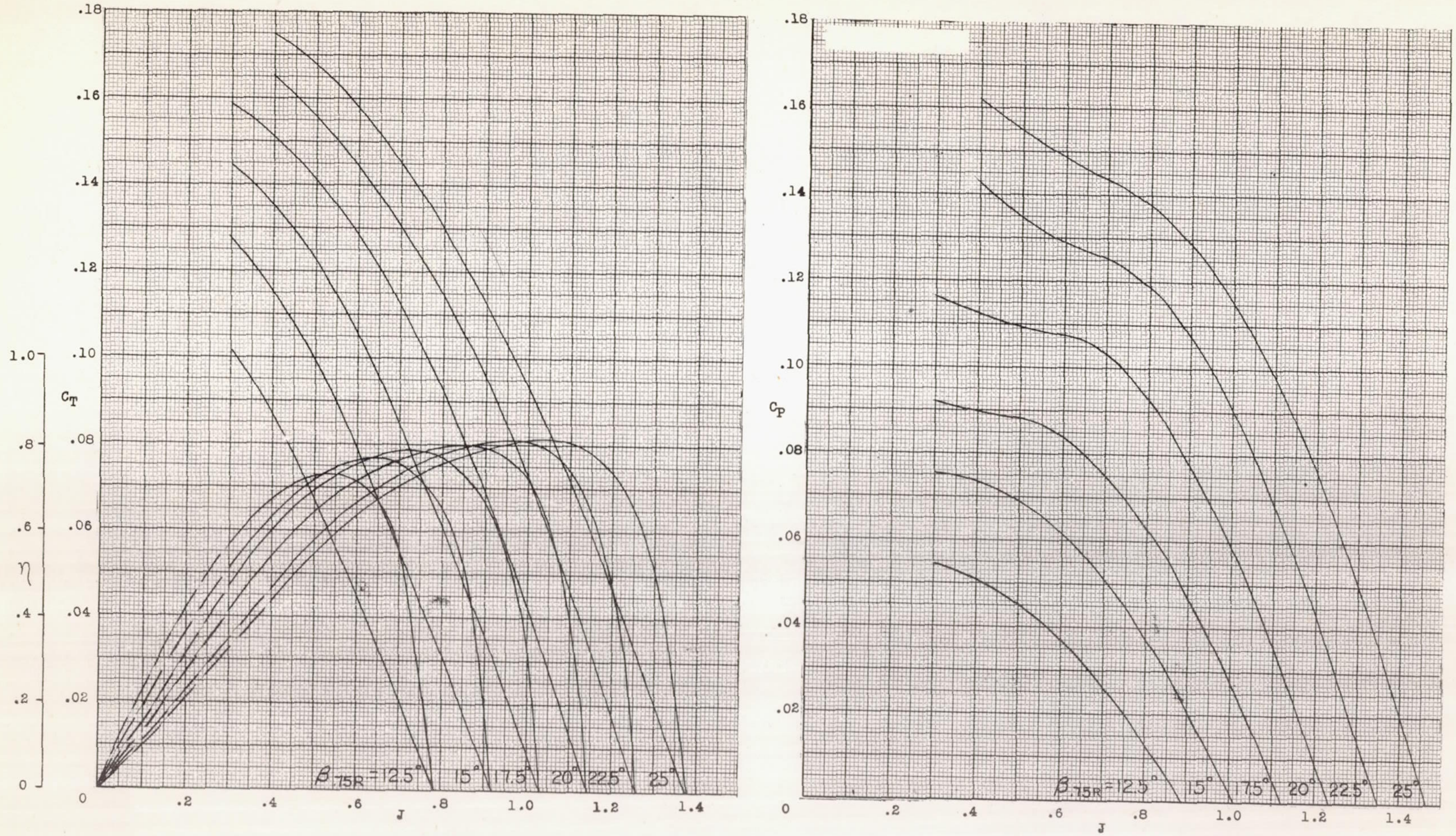


(b) $\delta_f = 20°$

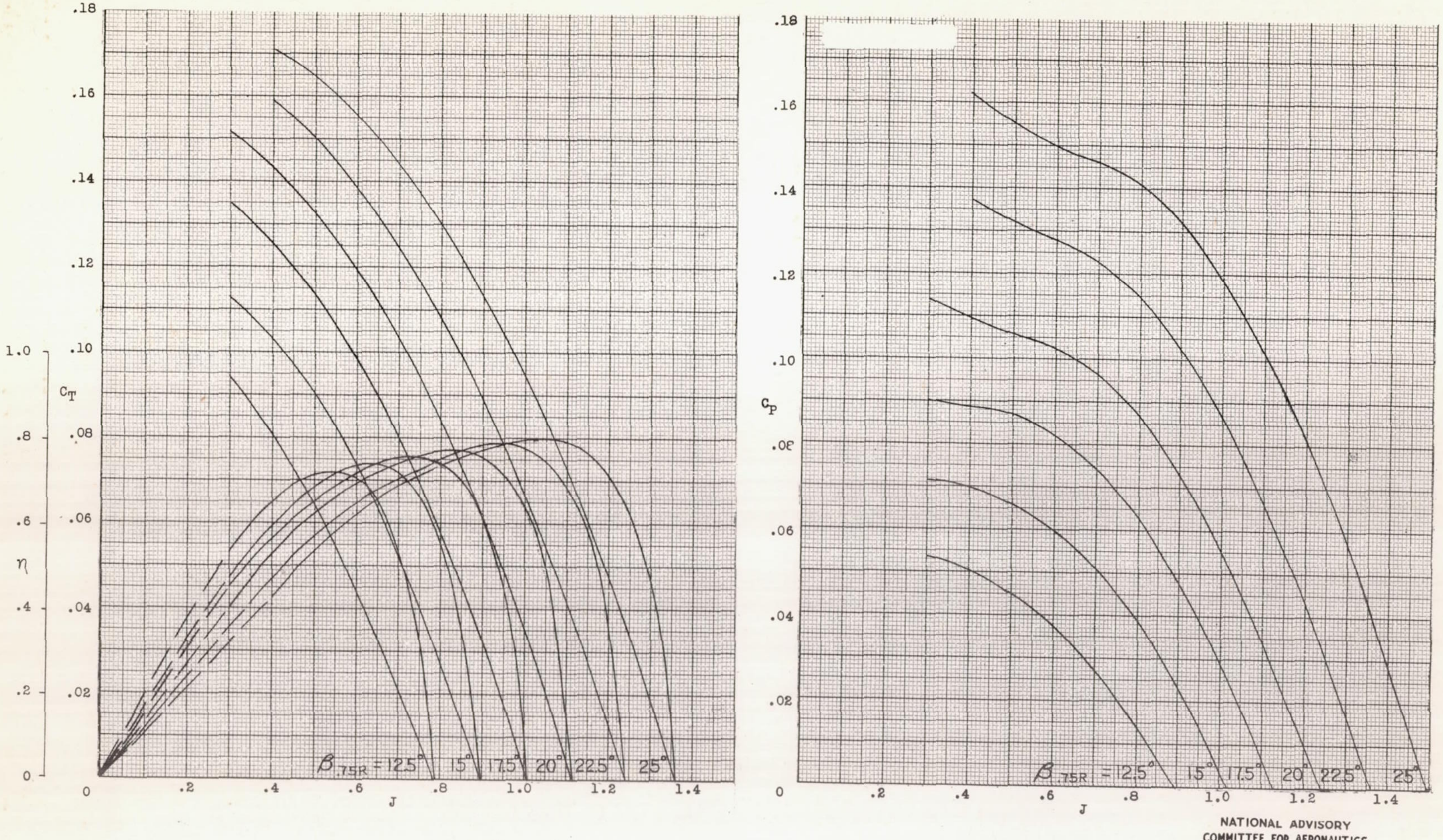
Figure 6.- Continued.

L-533



(c) $\delta_f = 30°$

Figure 6.- Continued.



(d) $\delta_f = 40°$

Figure 6.- Concluded.

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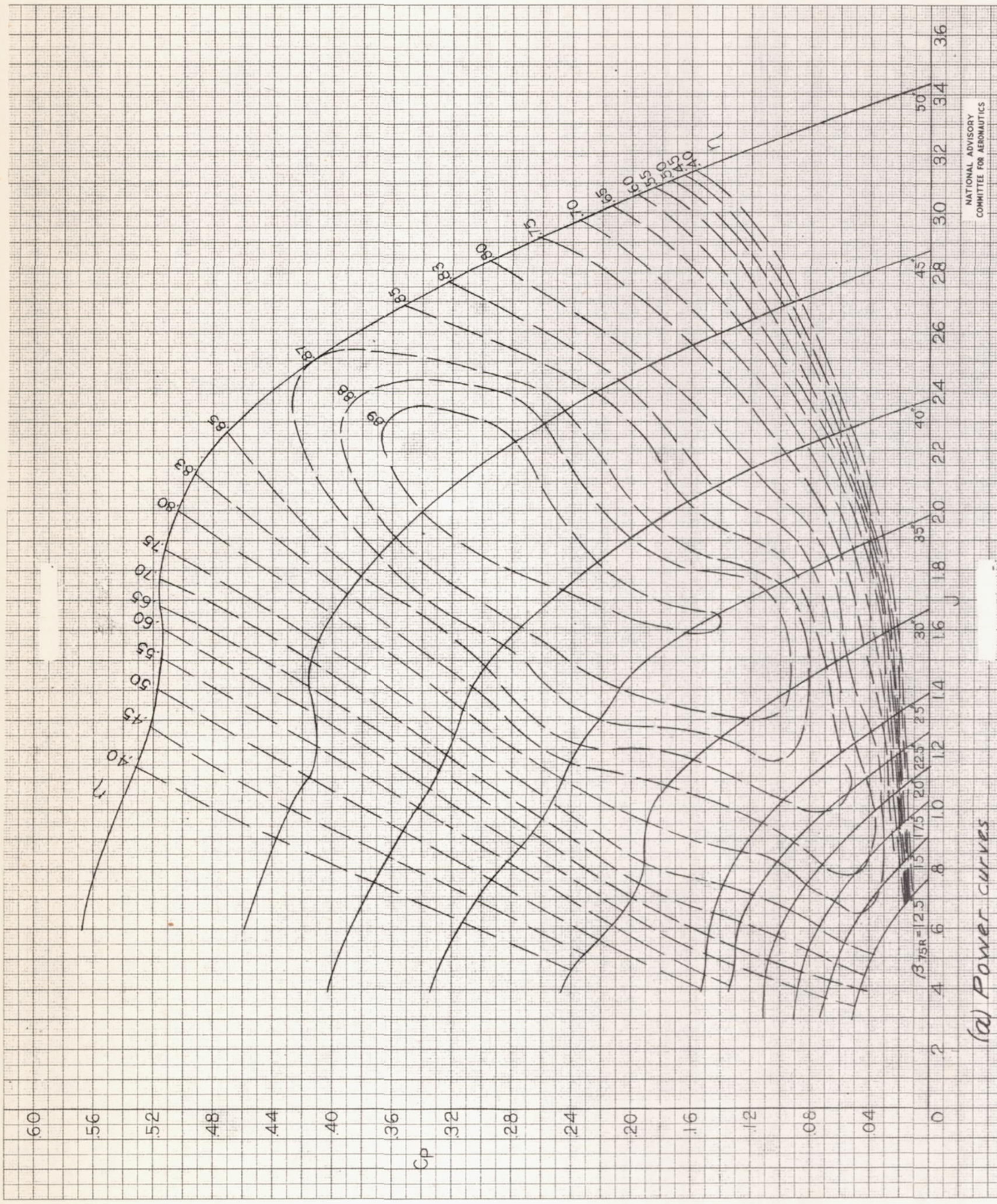
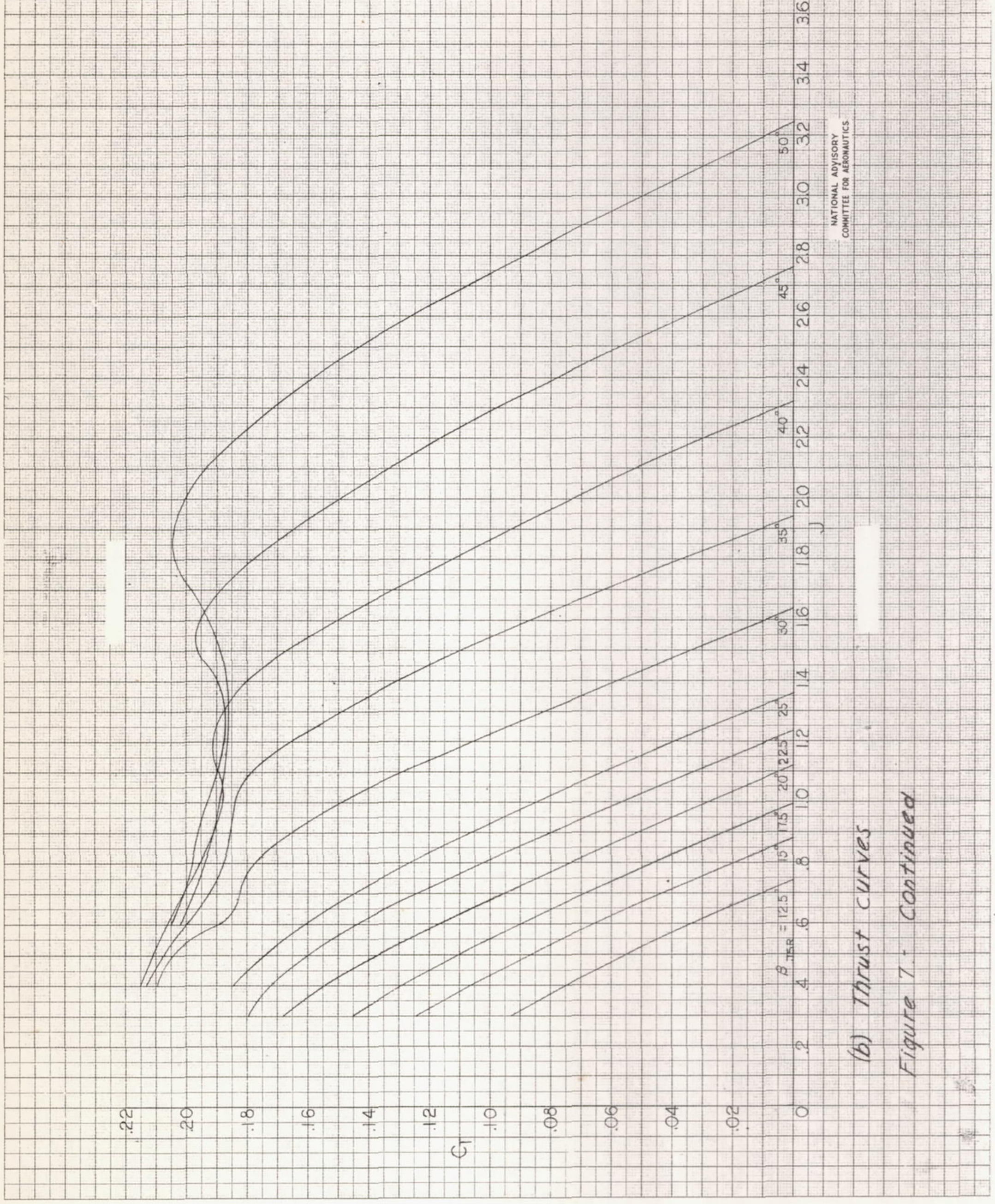


(a) Power curves

Figure 7.- Propeller characteristics, Clark Y, Landing gear retracted, $\delta_f = 0°$

L-533



(b) Thrust curves

Figure 7.- Continued

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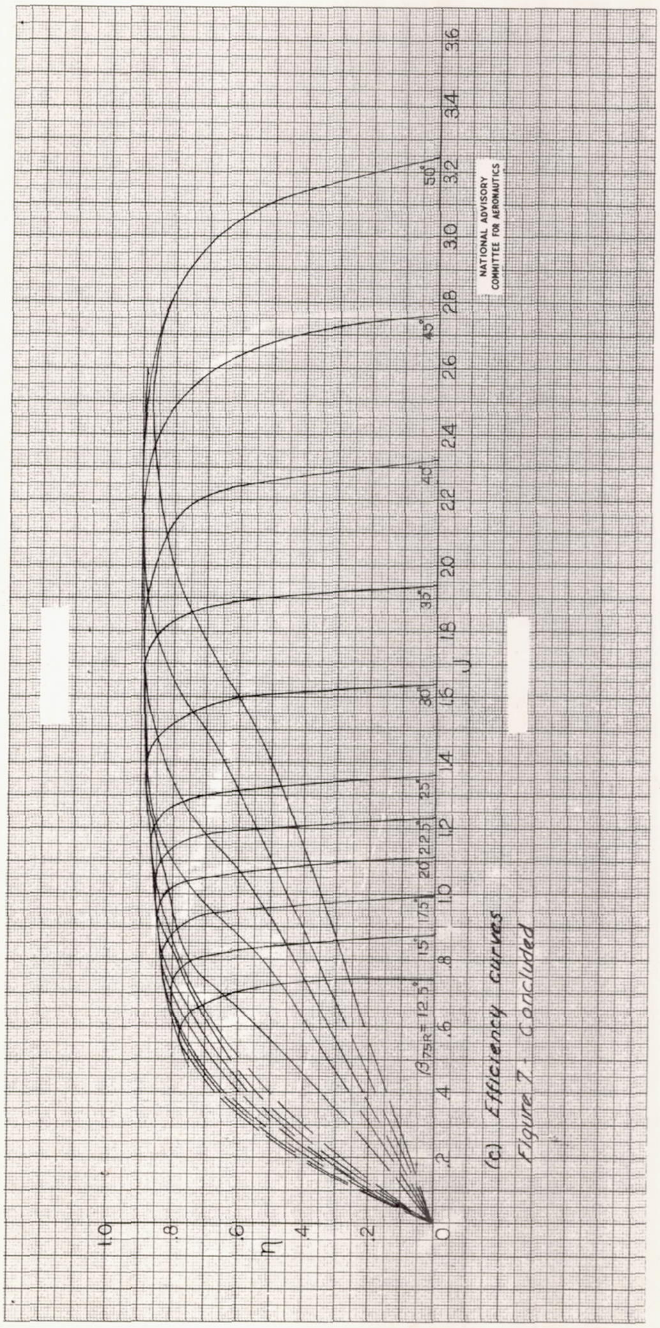
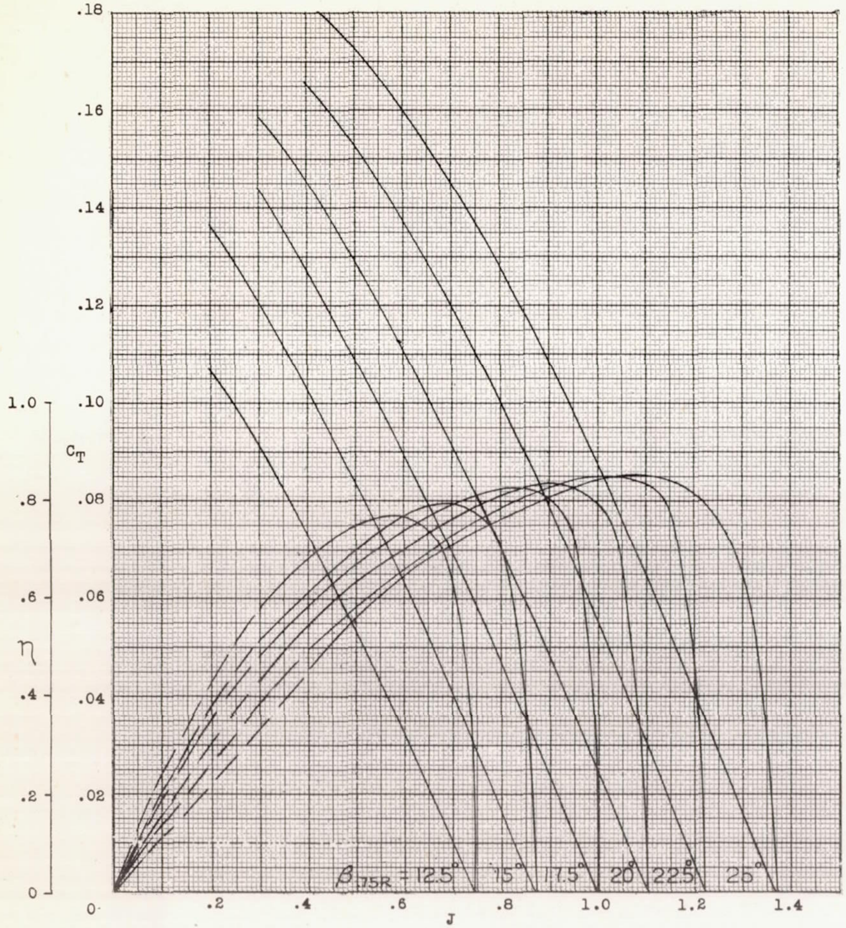
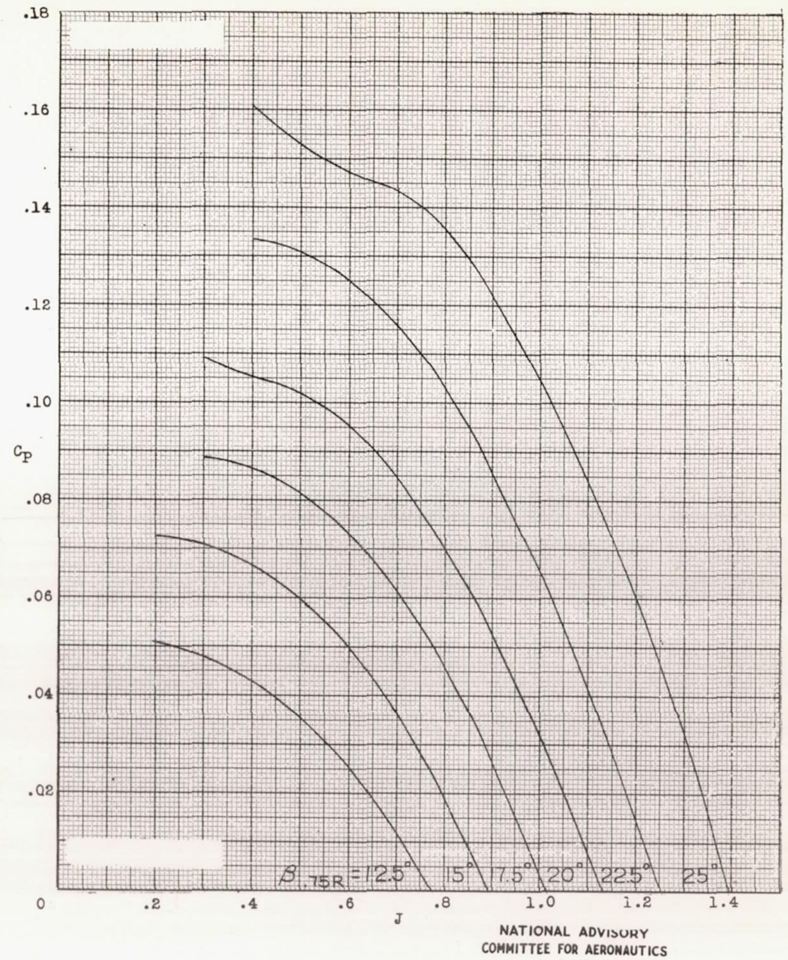


(c) Efficiency curves

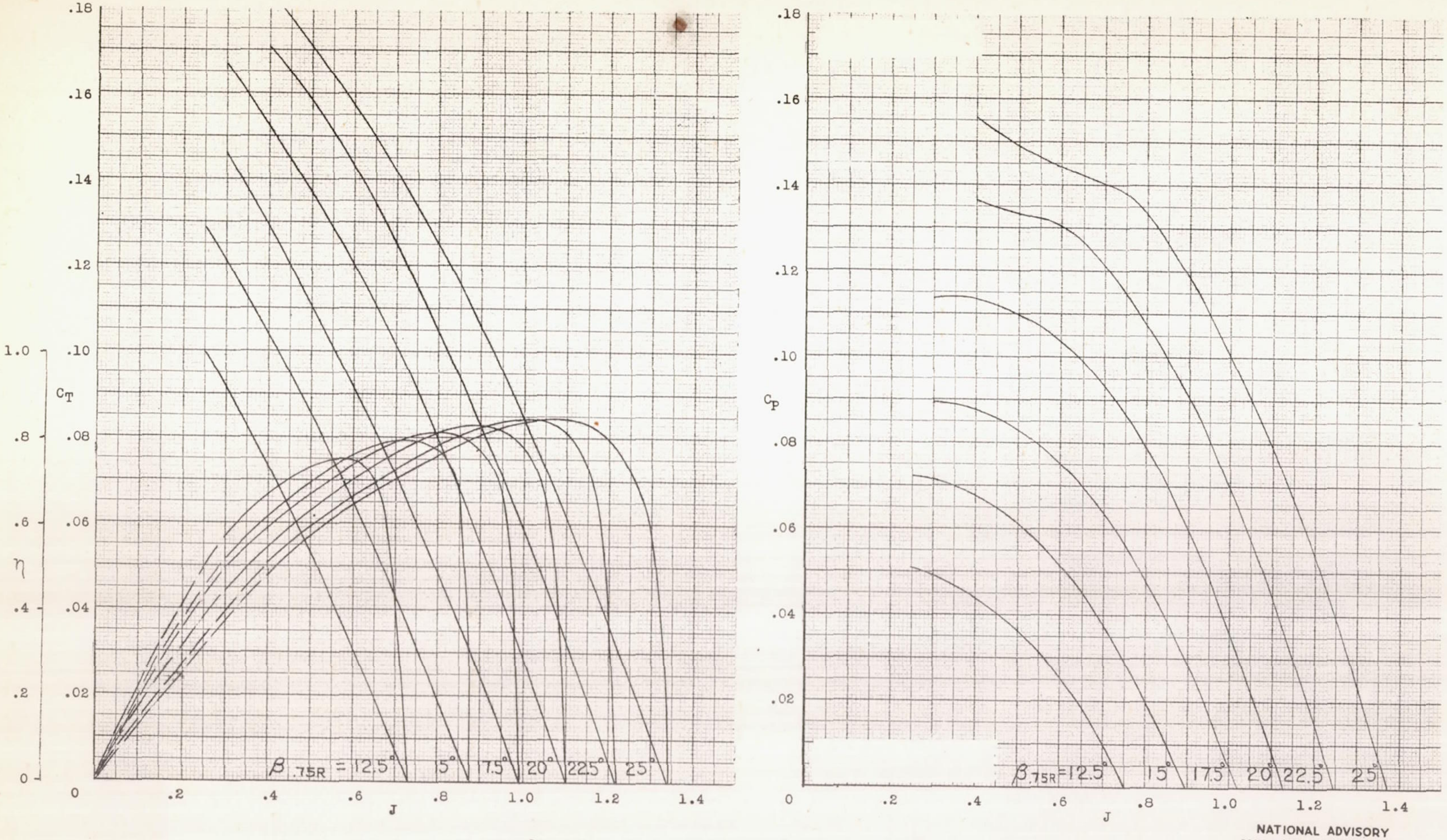
Figure 7. Concluded





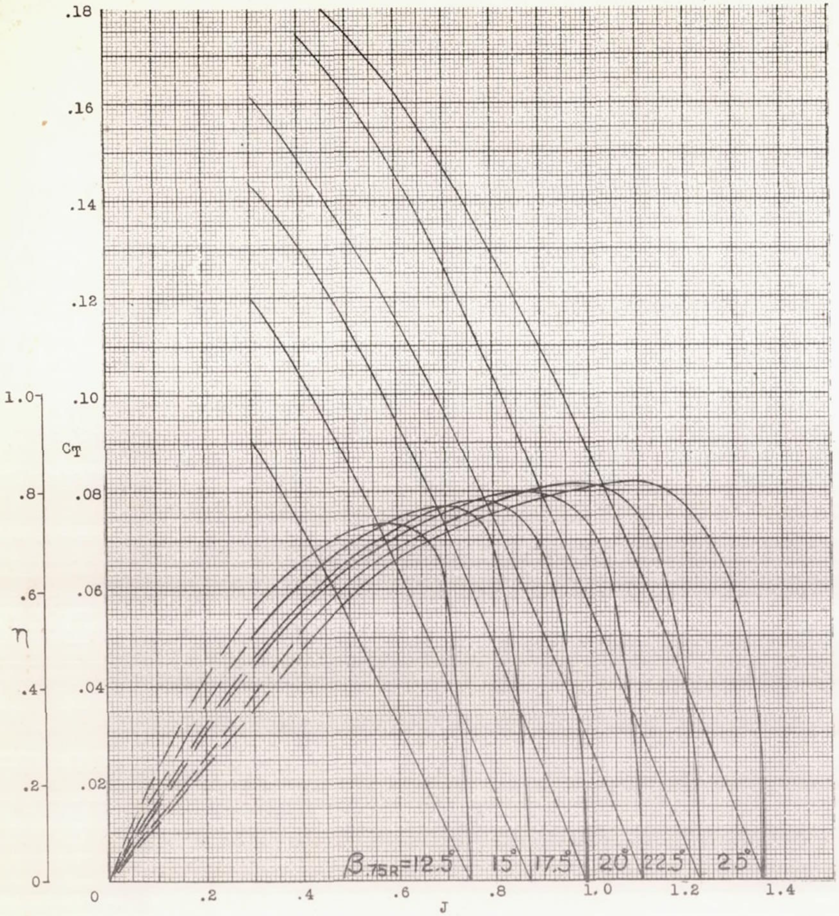
(a) $\delta_f = 10°$

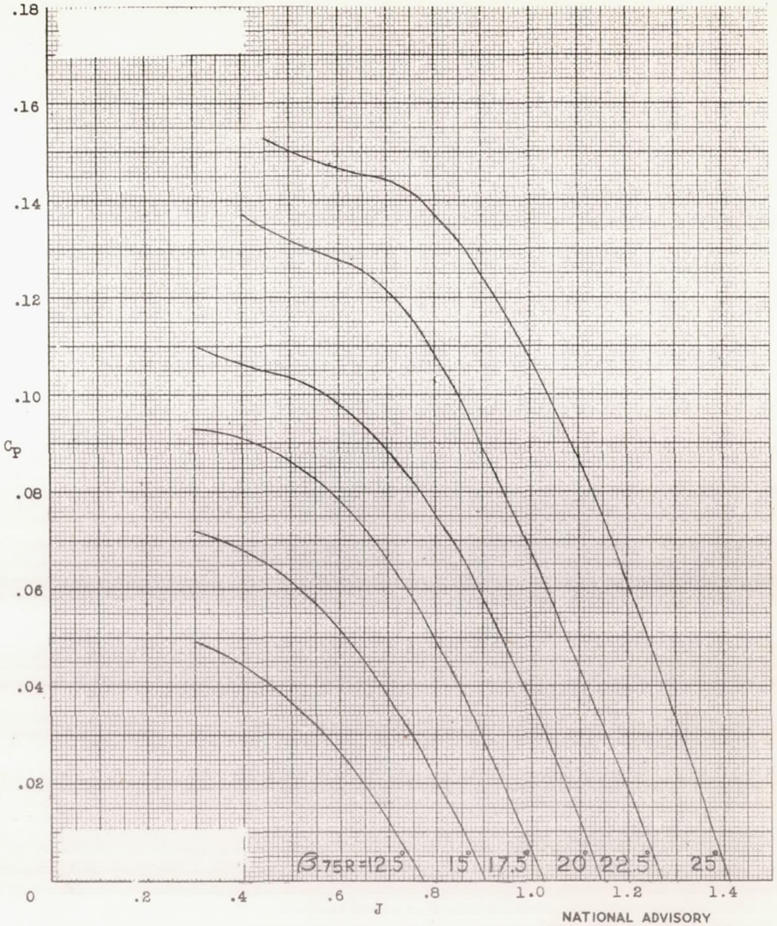
Figure 8.- Propeller characteristics, Clark Y, landing gear retracted.



(b) $\delta_f = 20°$

Figure 8.- Continued.





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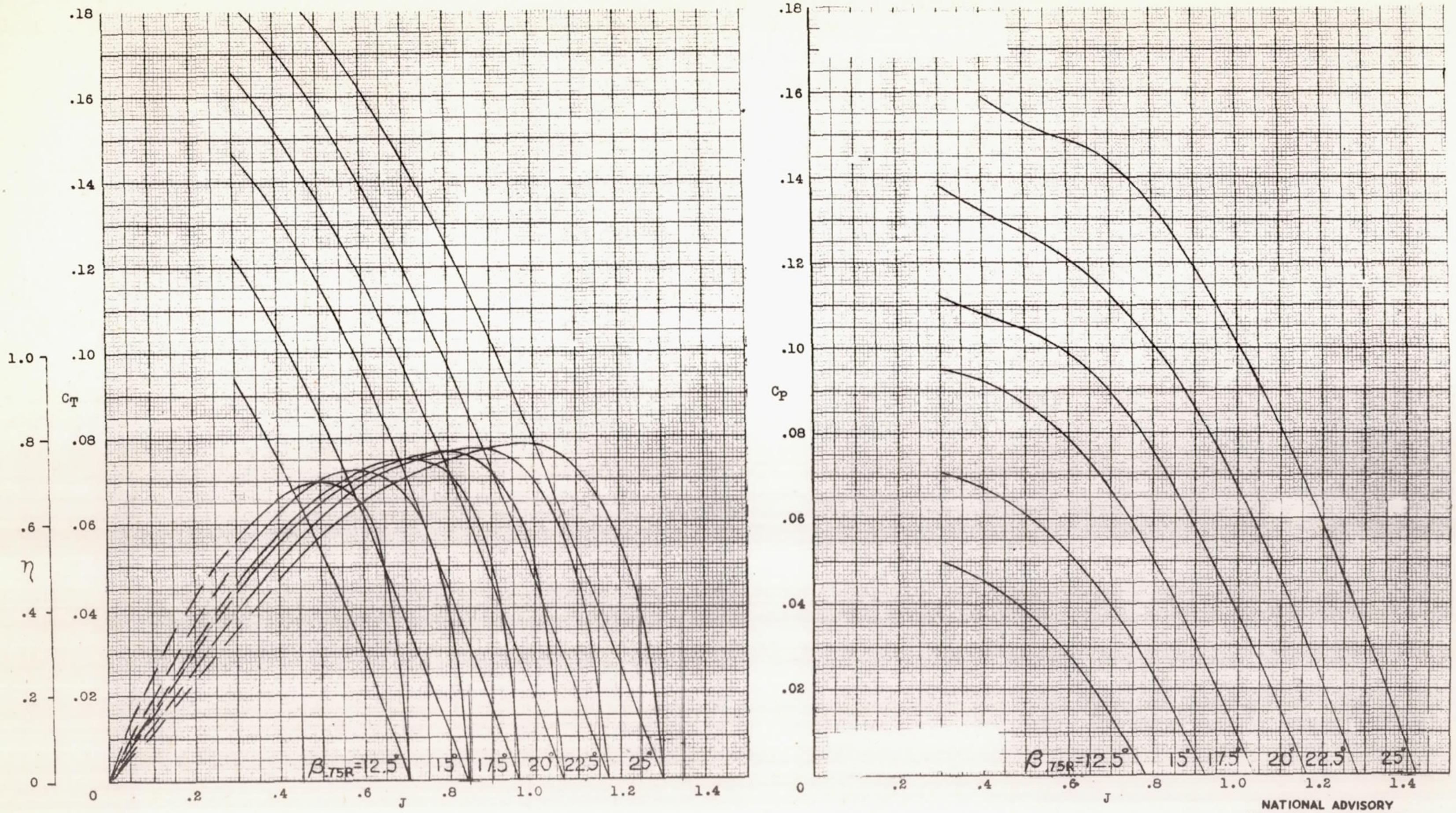
(c) $\delta_f = 30°$

Figure 8.- Continued.



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(d) $\delta_f = 40^{\circ}$

Figure 8.- Concluded.

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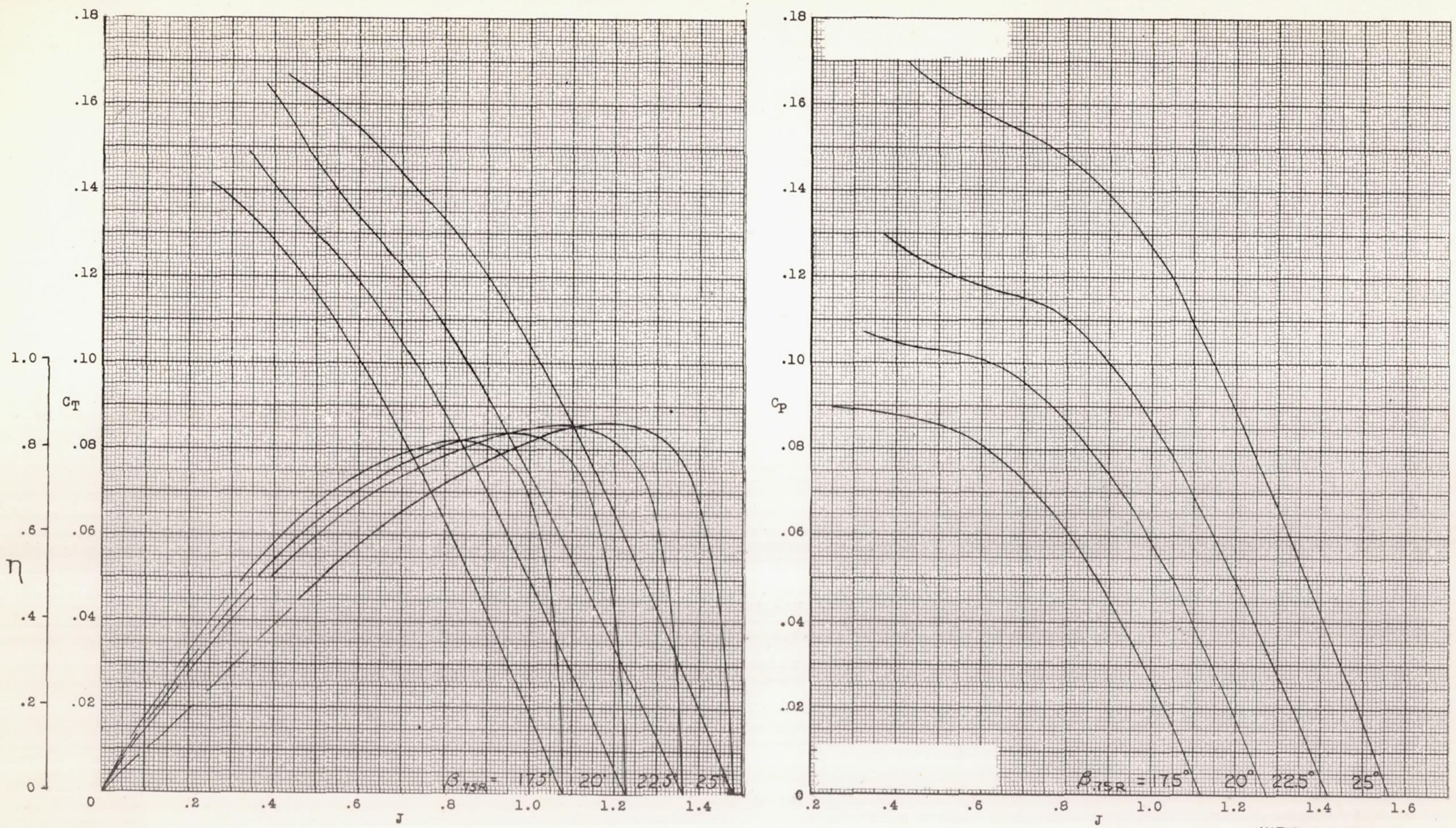

(a) $\delta_f = 0°$

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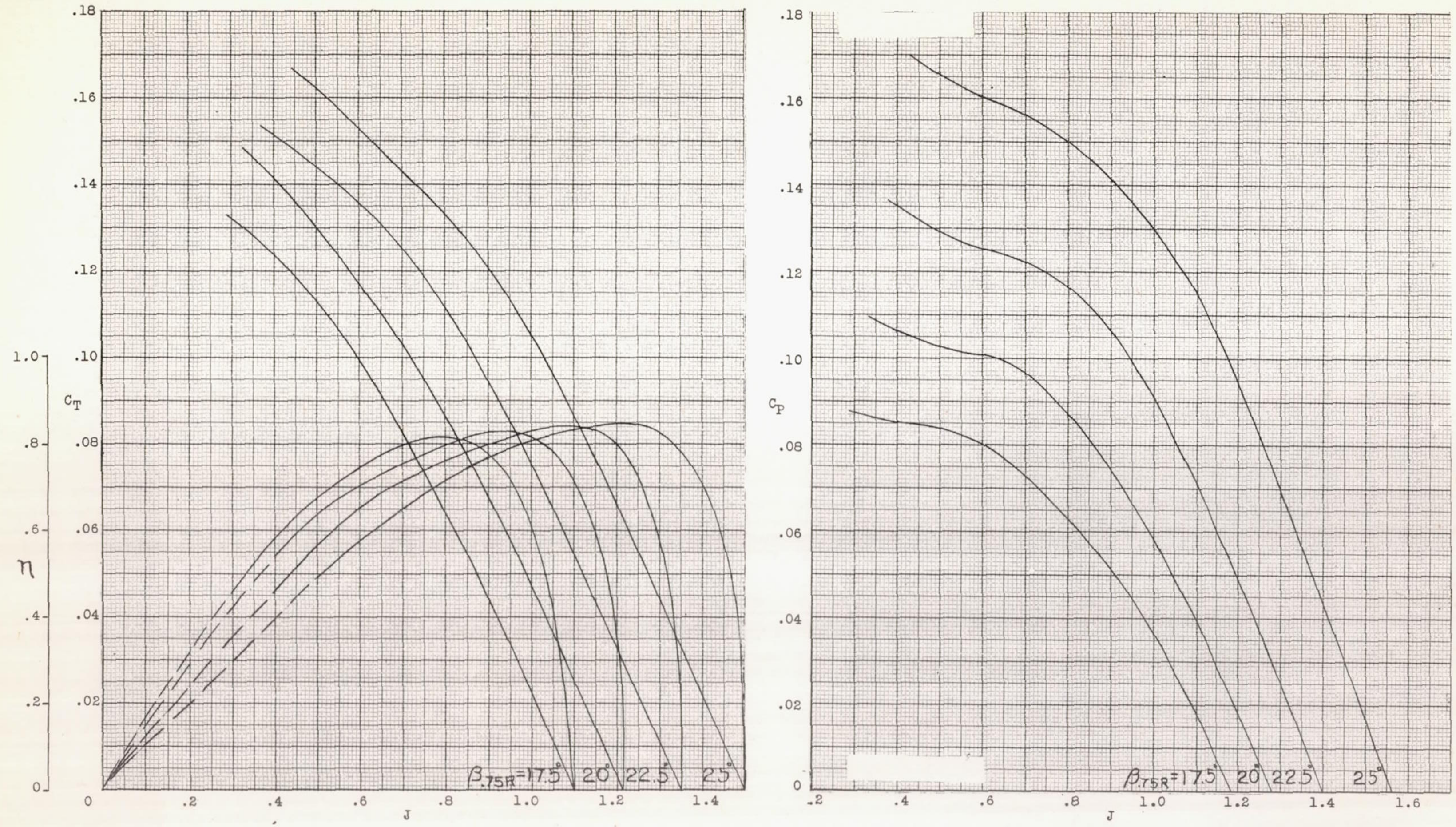
Figure 9.- Propeller characteristics, 16-series, landing gear extended.



(b) δ_f = 10°

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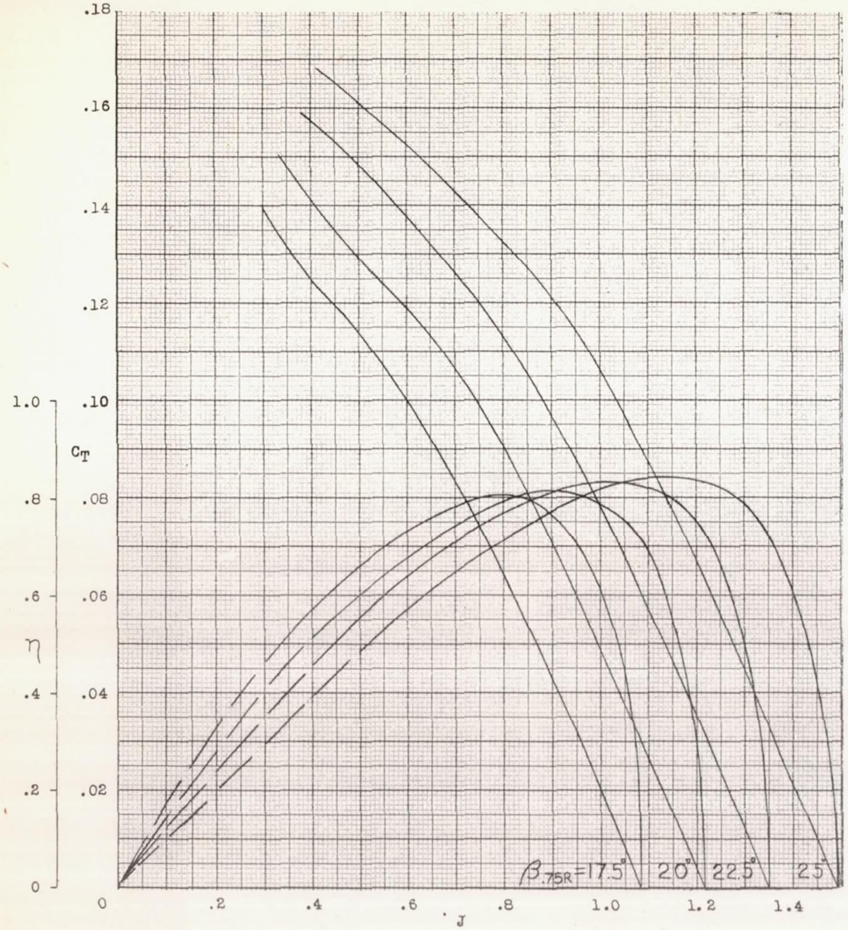
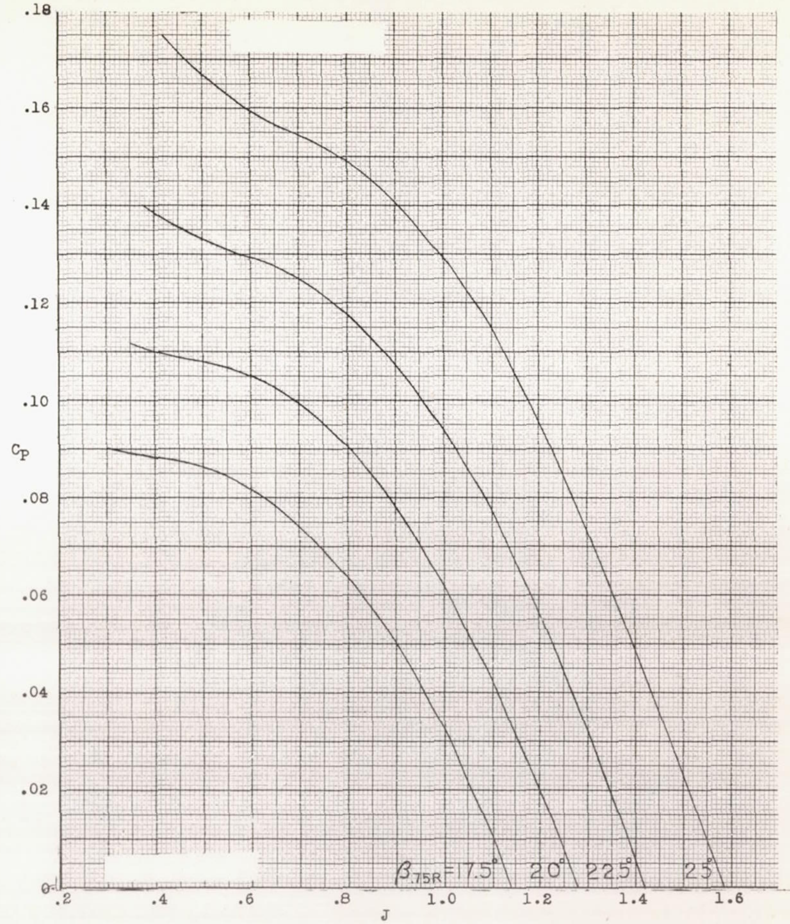
Figure 9.- Continued.





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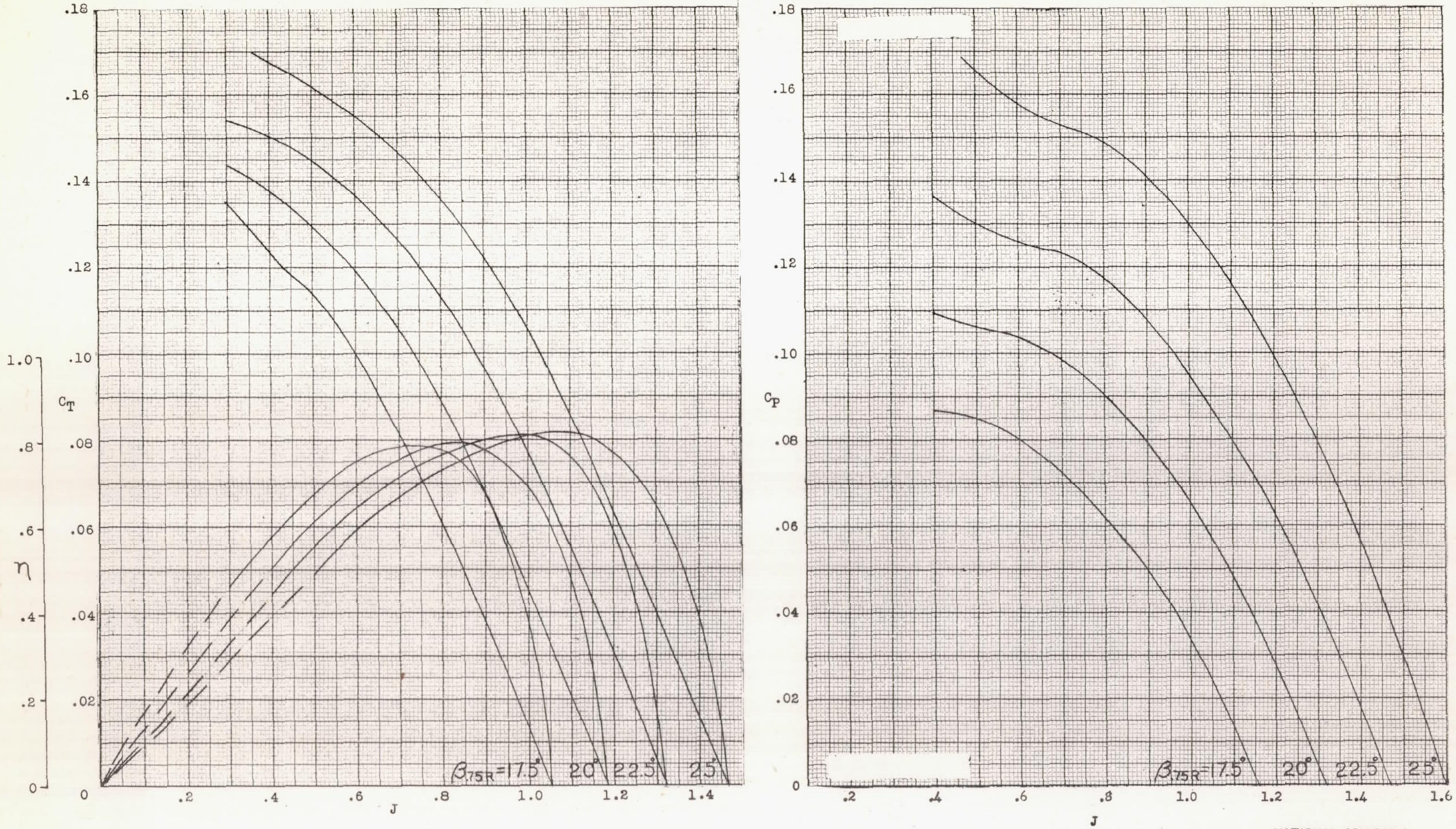
(c) $\delta_f = 20°$

Figure 9.- Continued.



(d) δ_f = 30°

Figure 9.- Continued.

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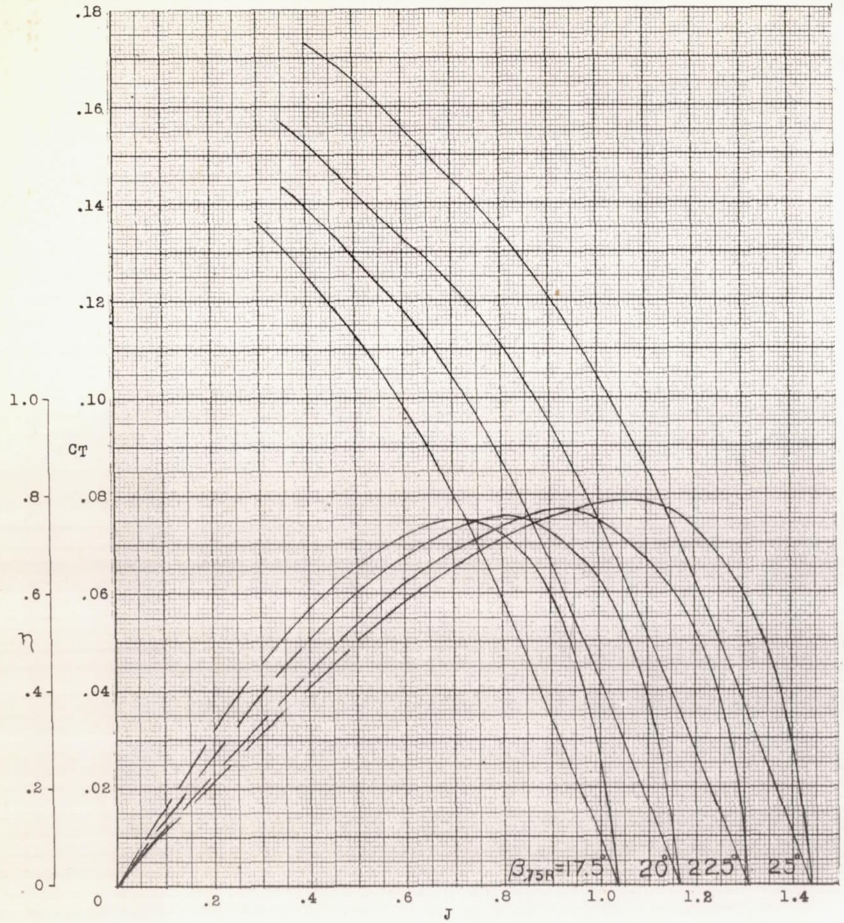

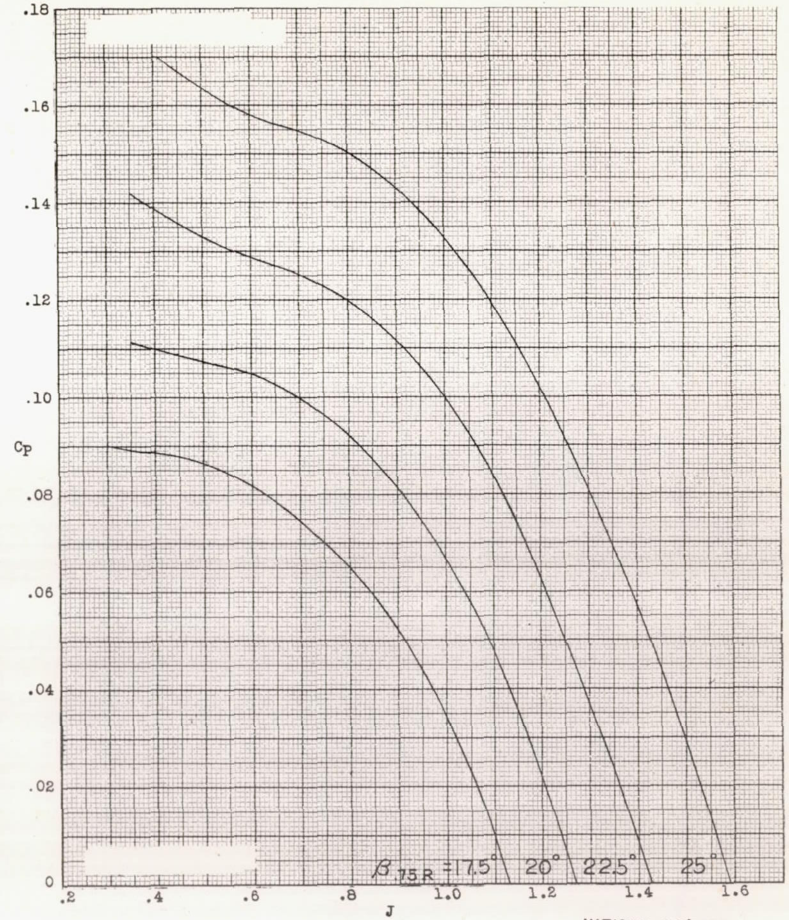

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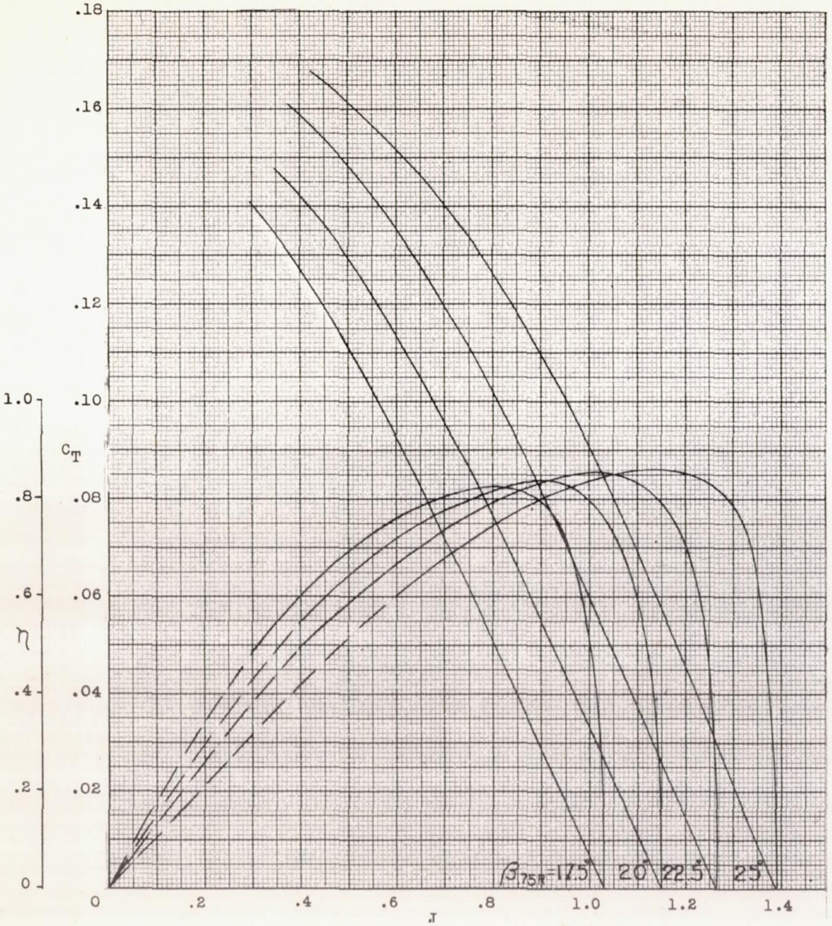
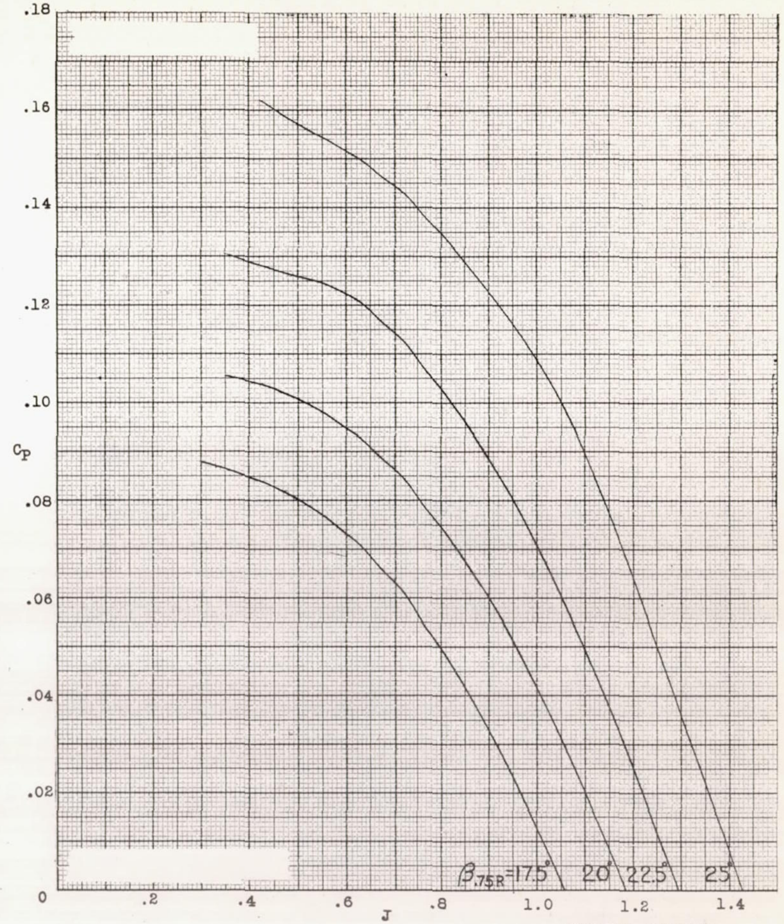
(e) $\delta_f = 40°$

Figure 9.- Concluded.





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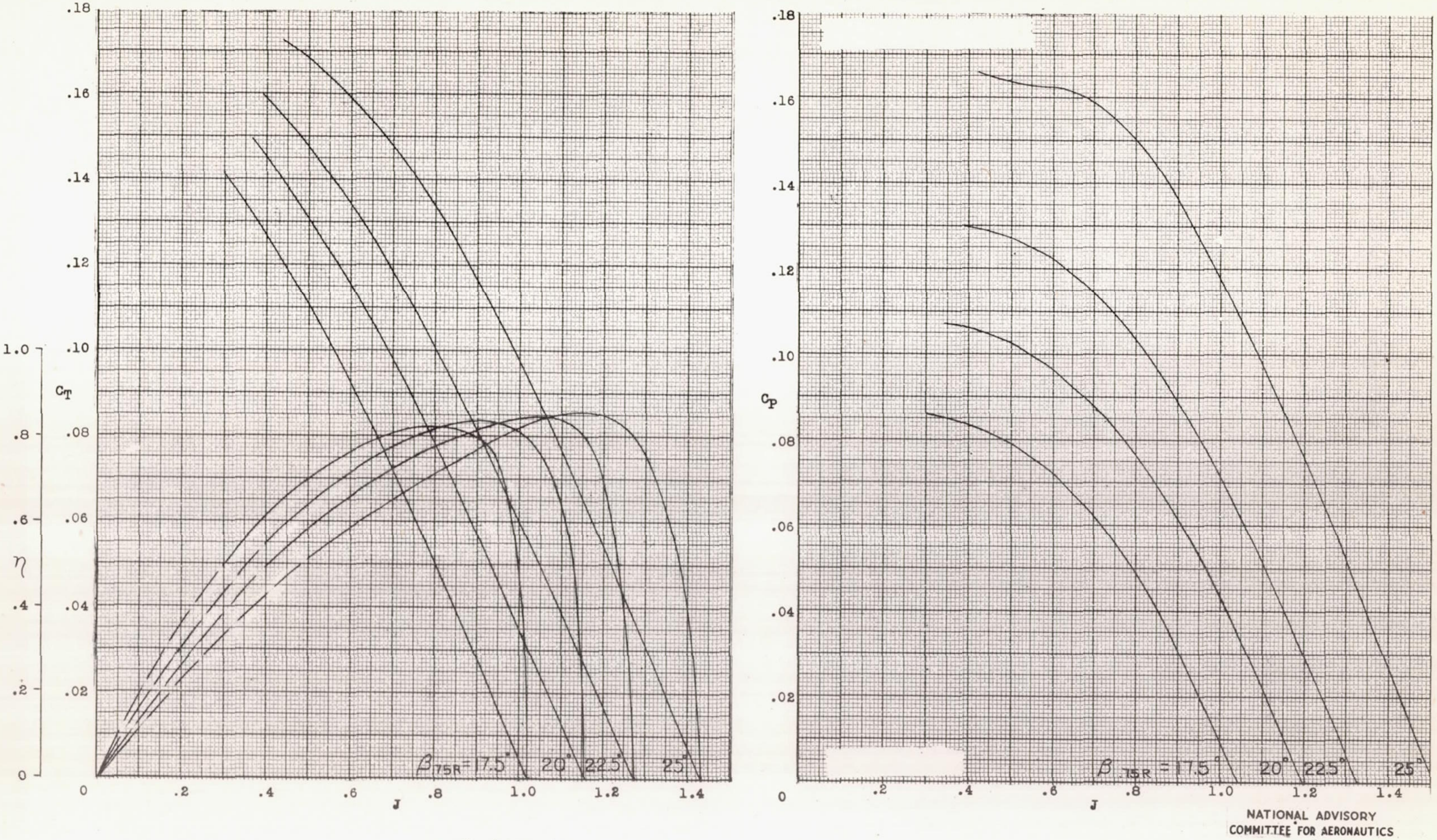
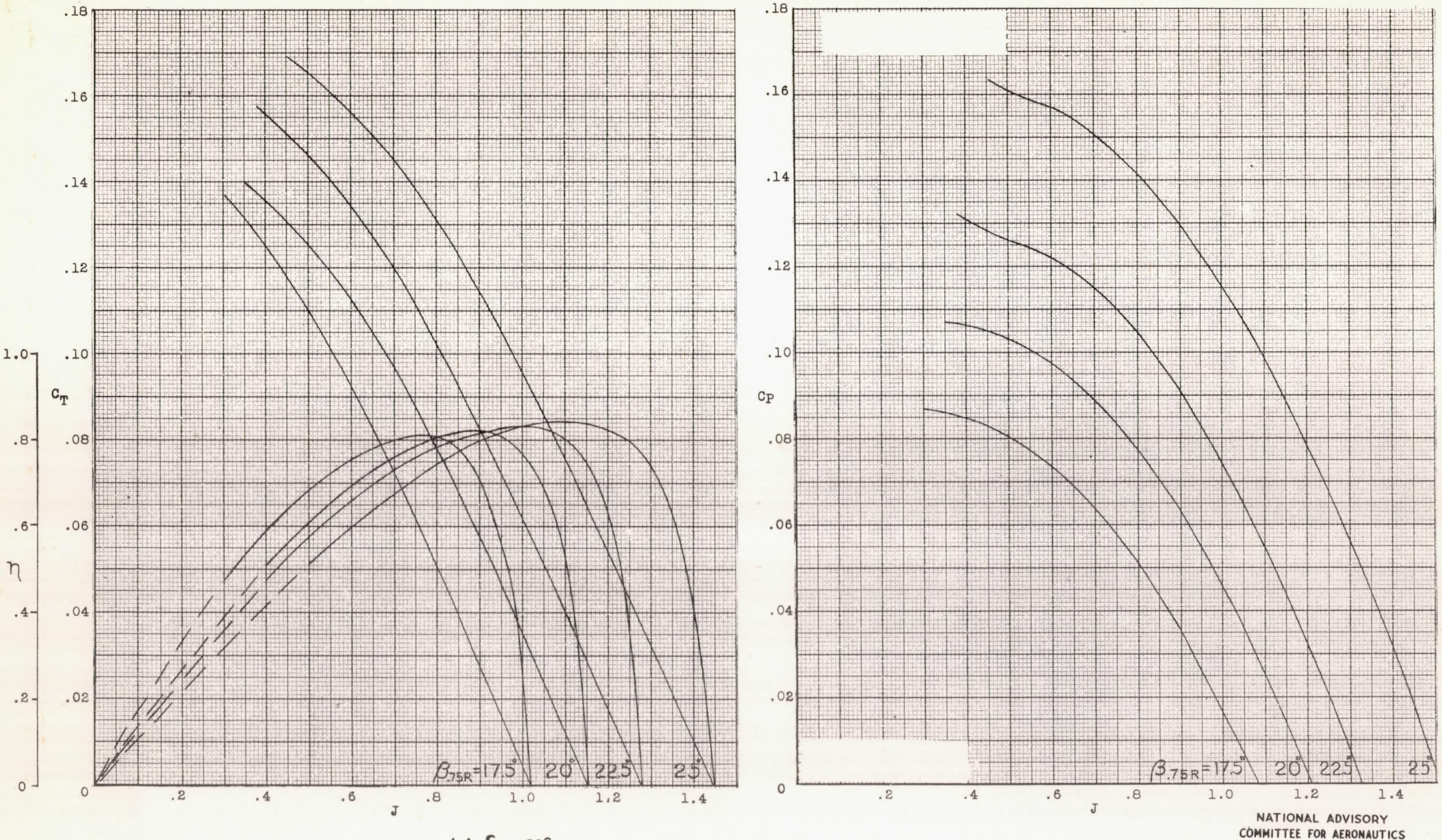
(a) $\delta_f = 0°$

Figure 10.- Propeller characteristics, Clark Y, landing gear extended.



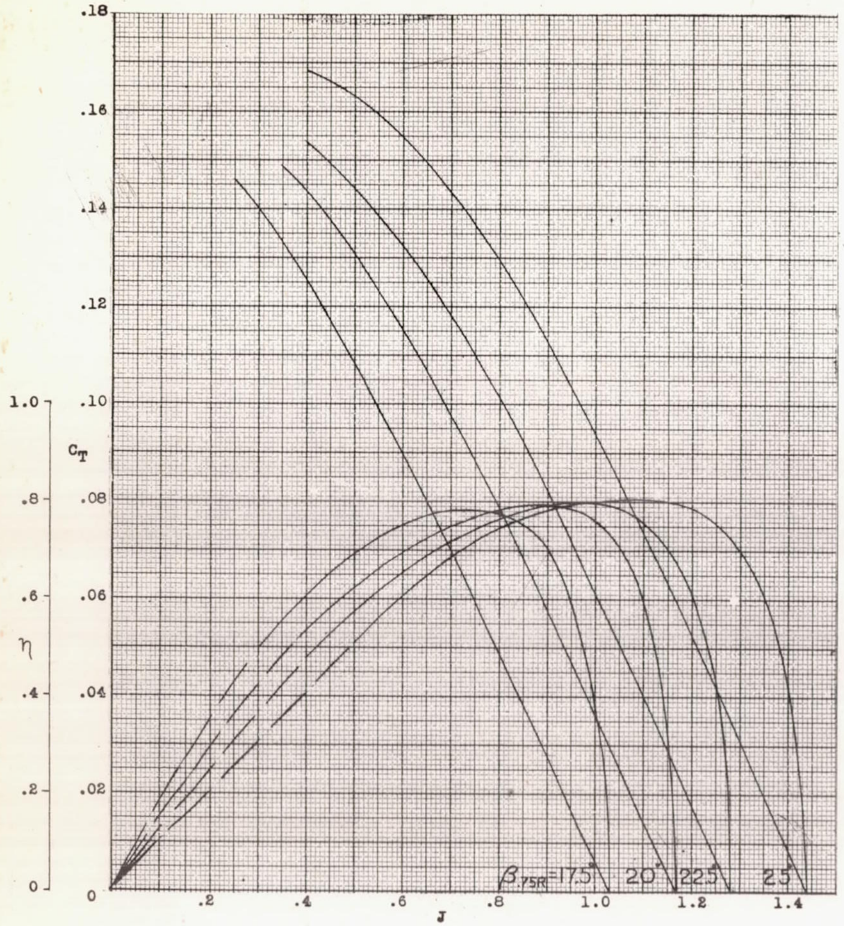
(b) $\delta_f = 10°$

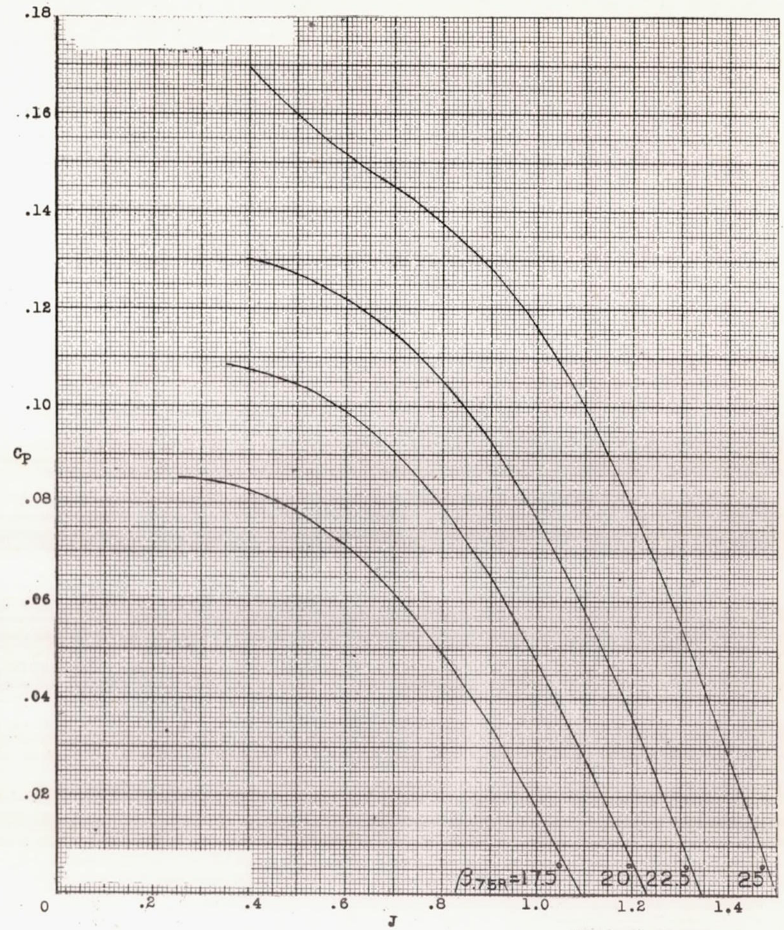
Figure 10.- Continued.



(c) δ_f = 20°

Figure 10.- Continued.





(d) $\delta_f = 30°$

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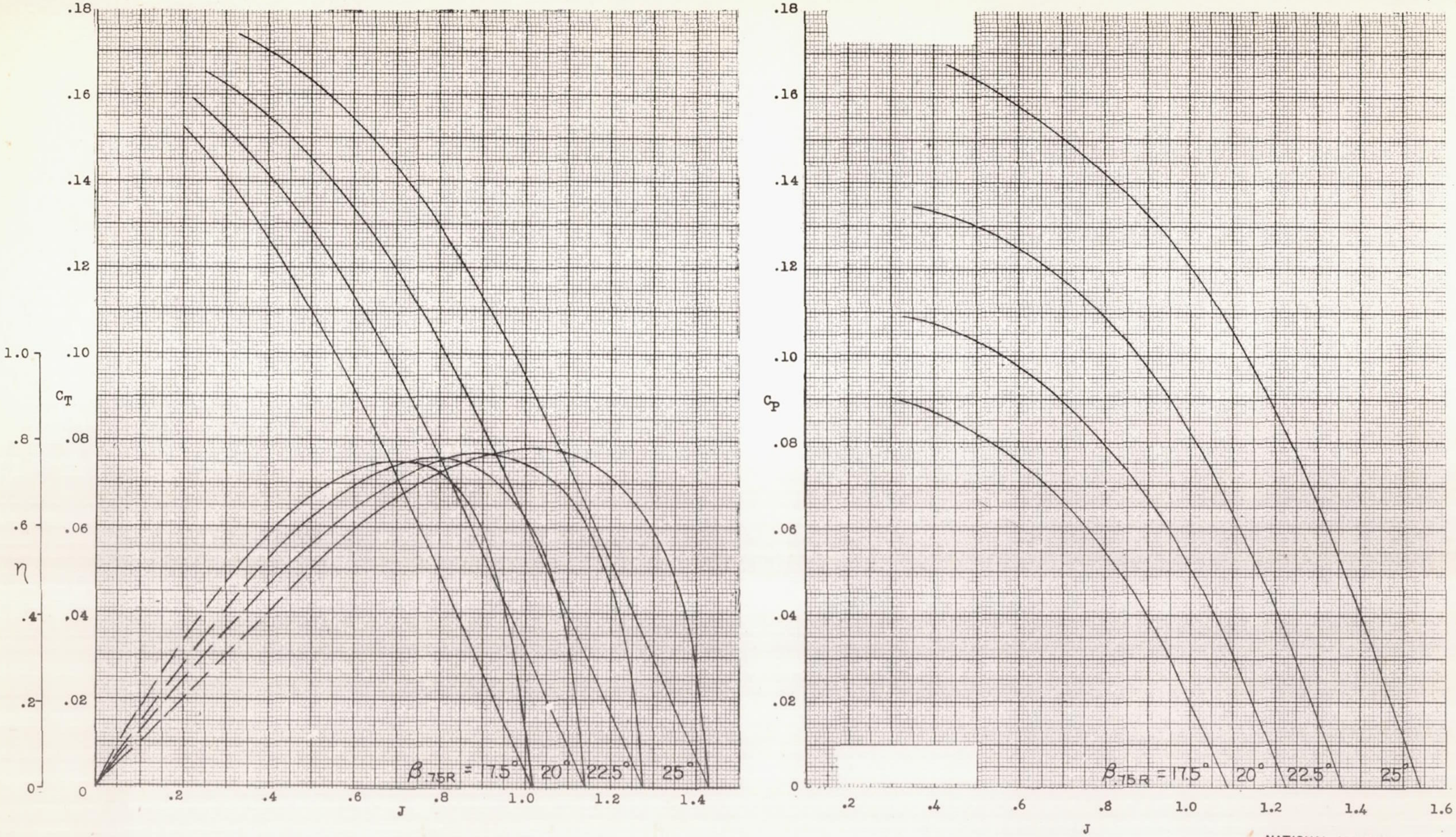
Figure 10.- Continued.



(e) $\delta_f = 40°$

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Figure 10.- Concluded.

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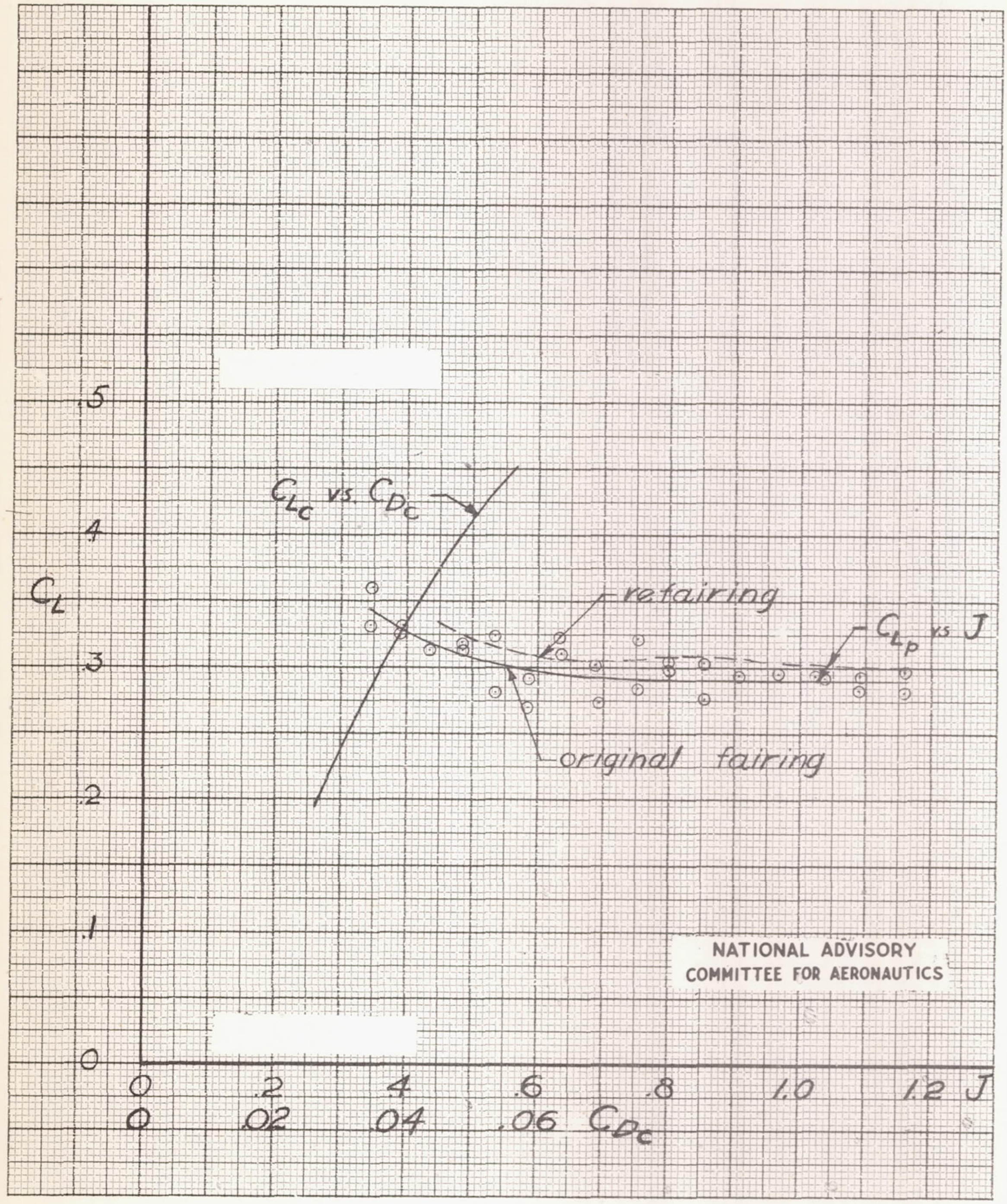

Figure 11.- Typical refairing necessary to obtain faired propeller characteristics; 16-series; δ_f = 10°; β, 20°; landing gear retracted.

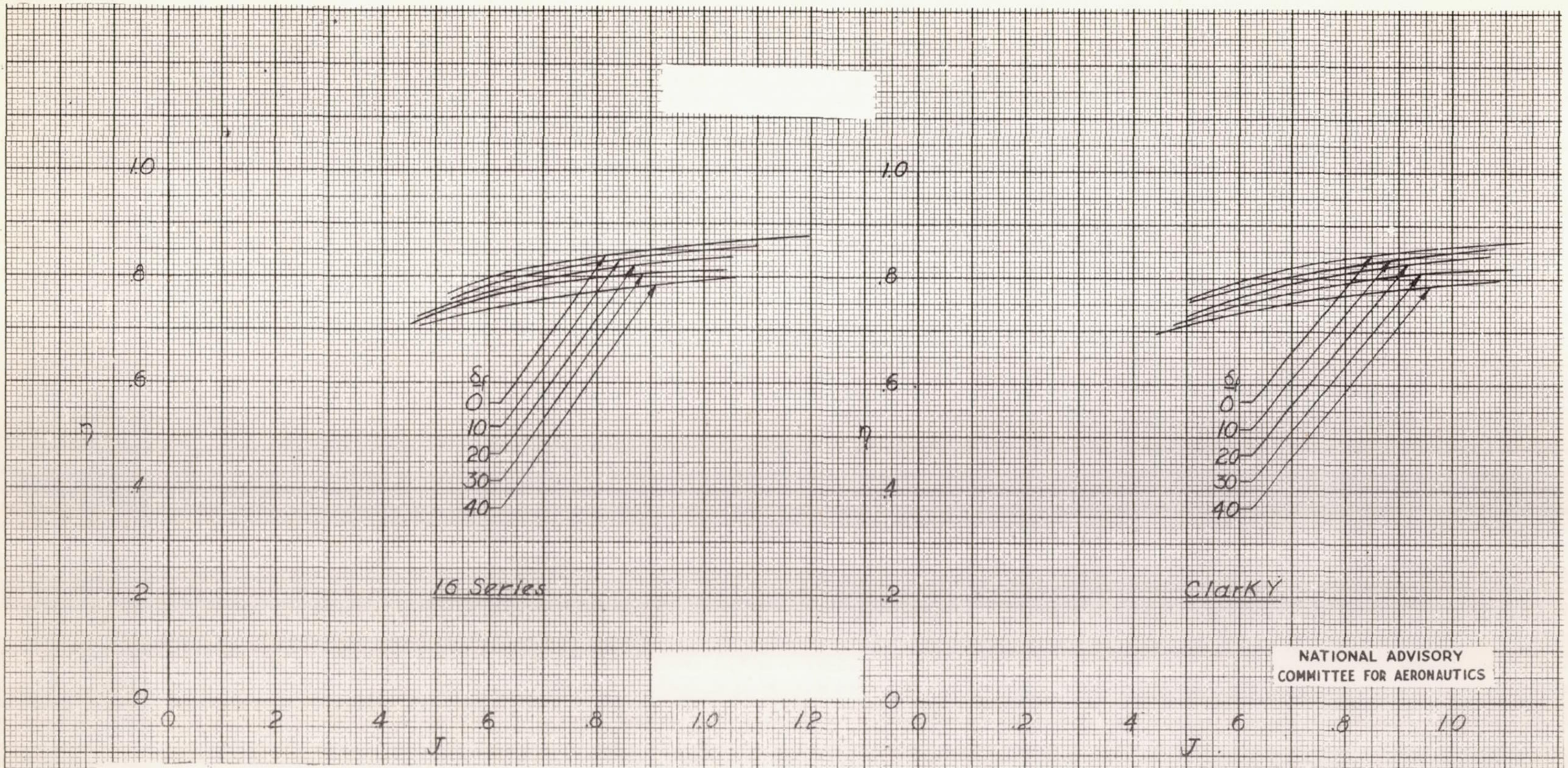

Figure 12.- Peak efficiency envelopes, landing gear retracted.

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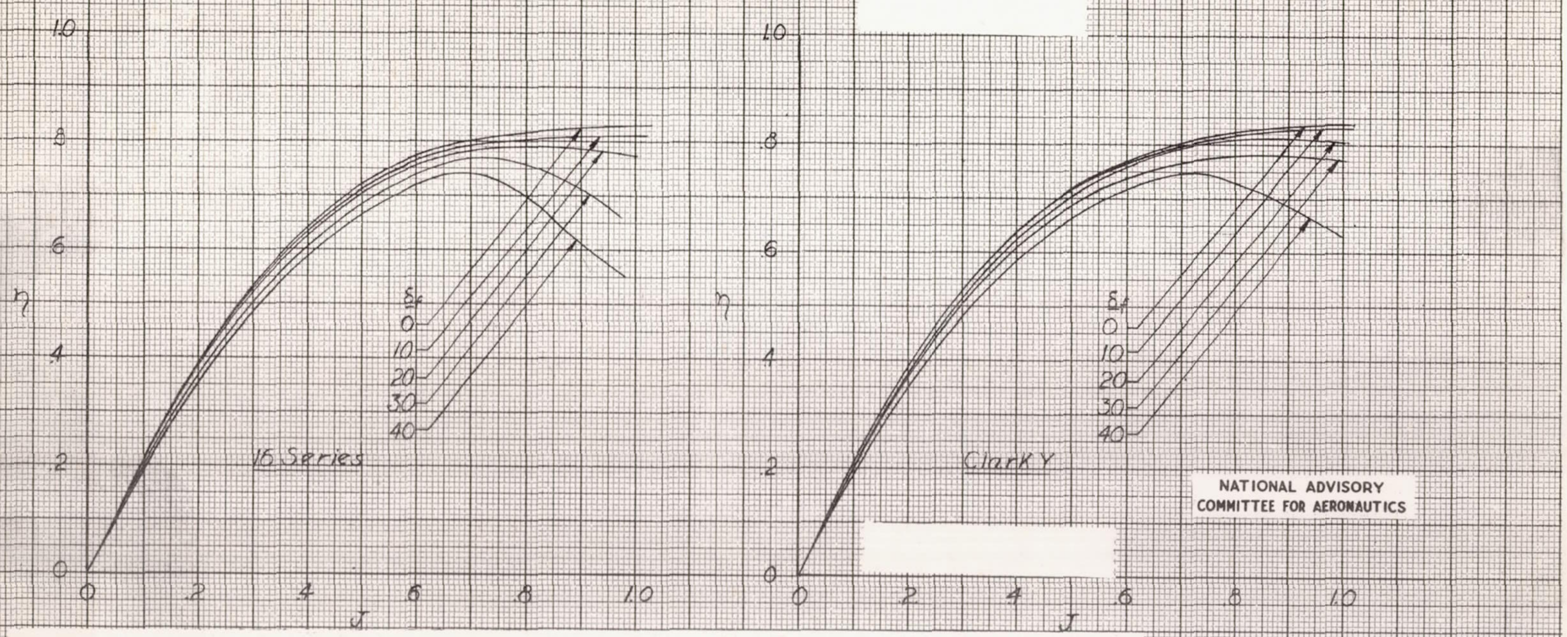


Figure 13.- Effect of flap deflection upon efficiency for C_p = .055. Landing gear retracted.

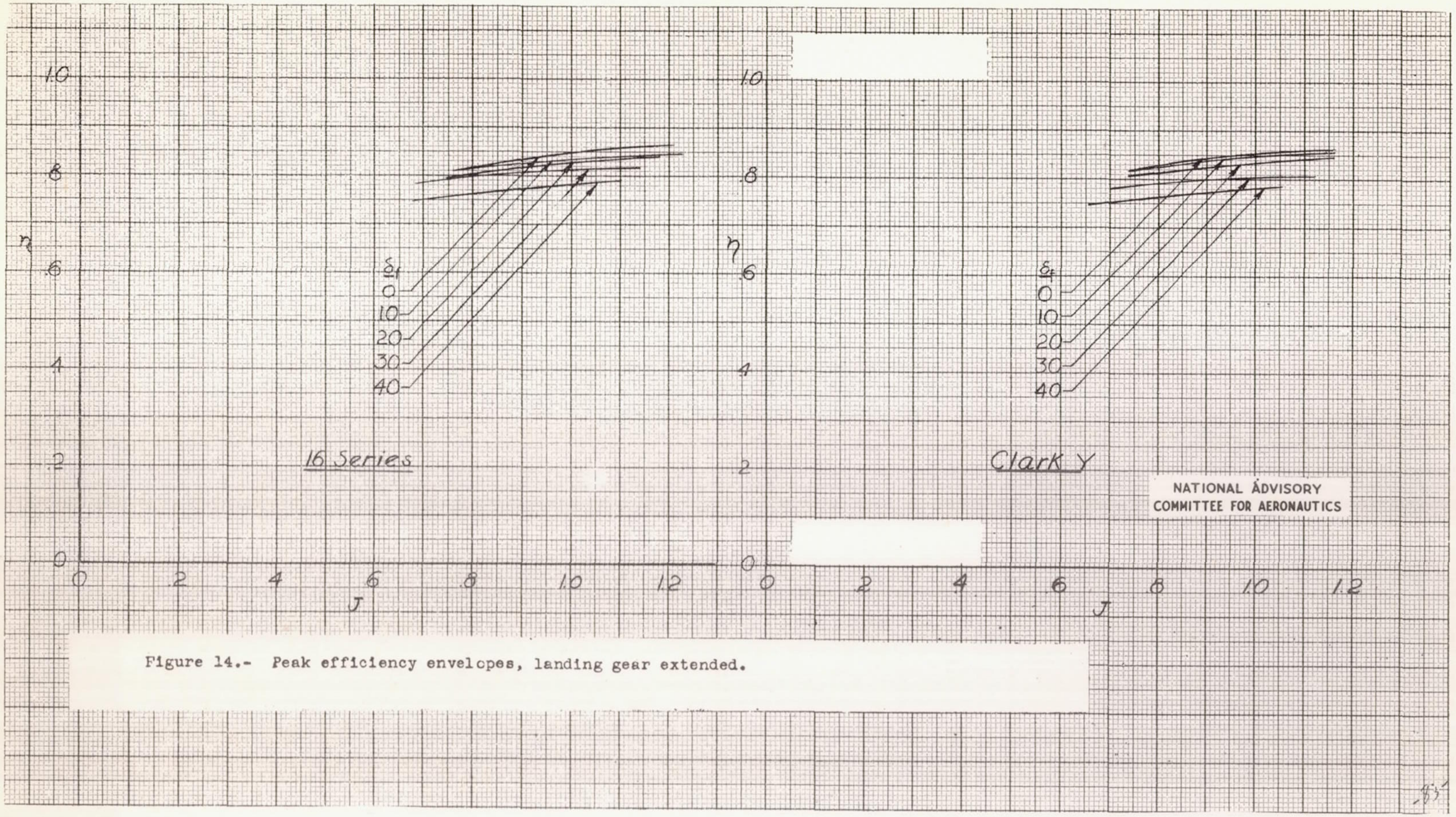


Figure 14.- Peak efficiency envelopes, landing gear extended.

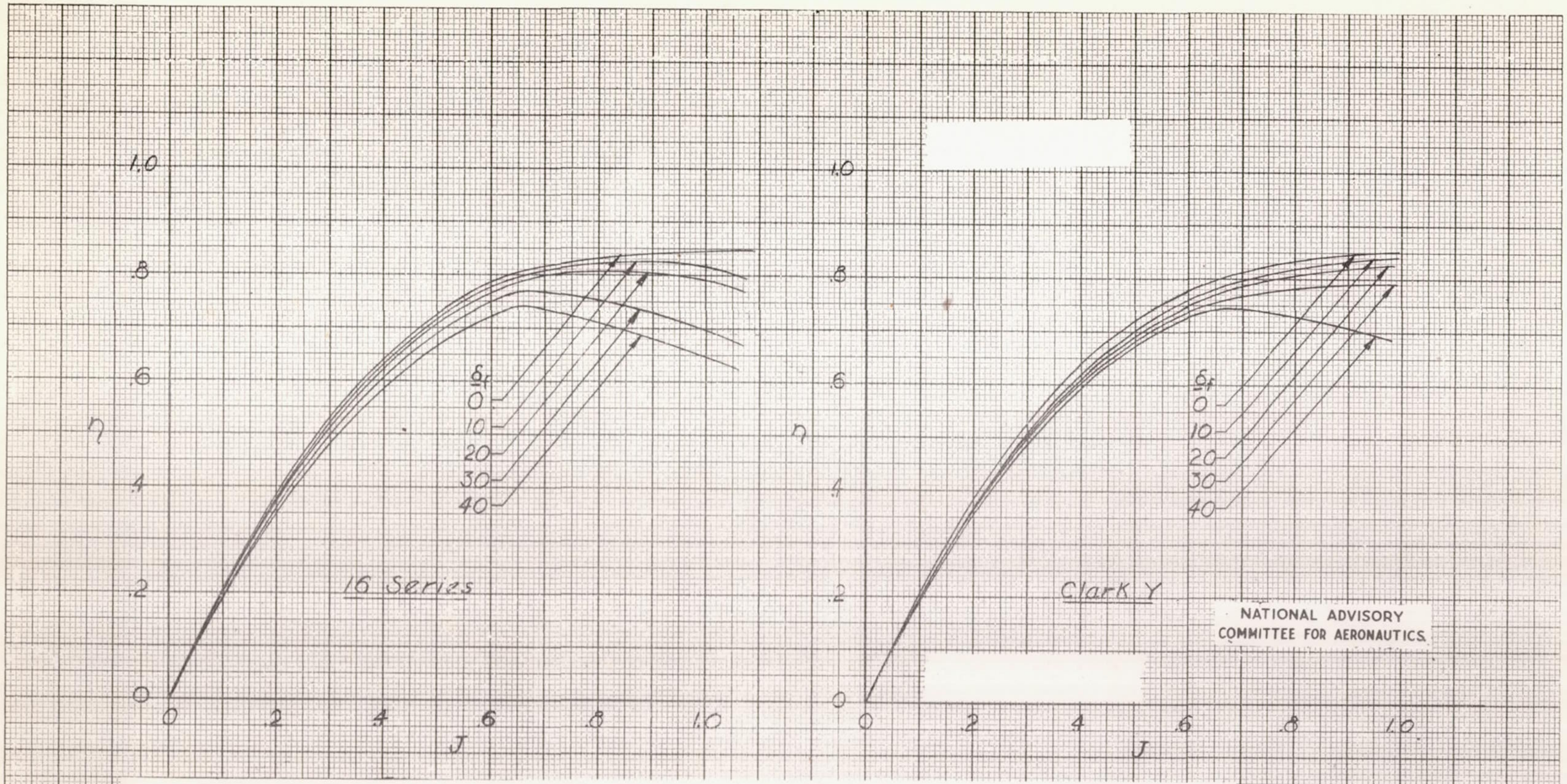
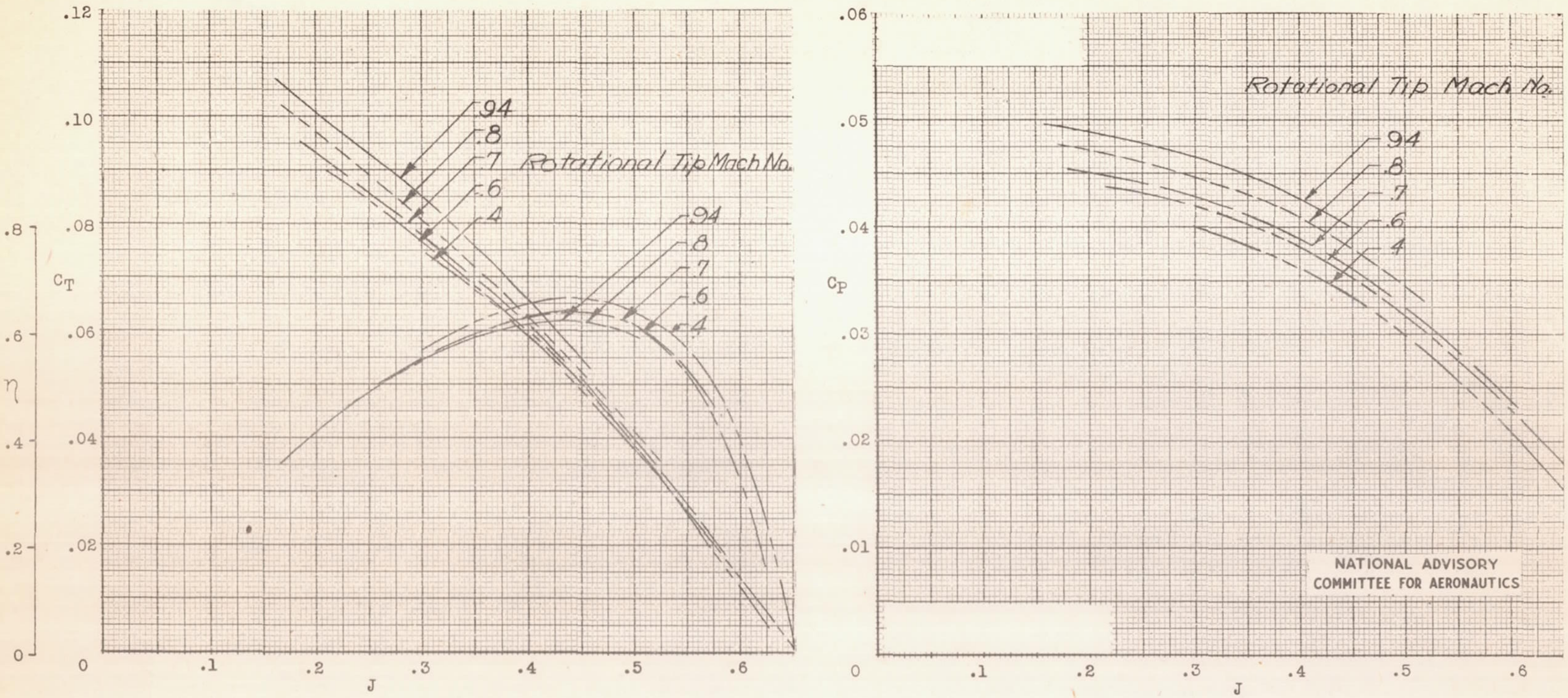
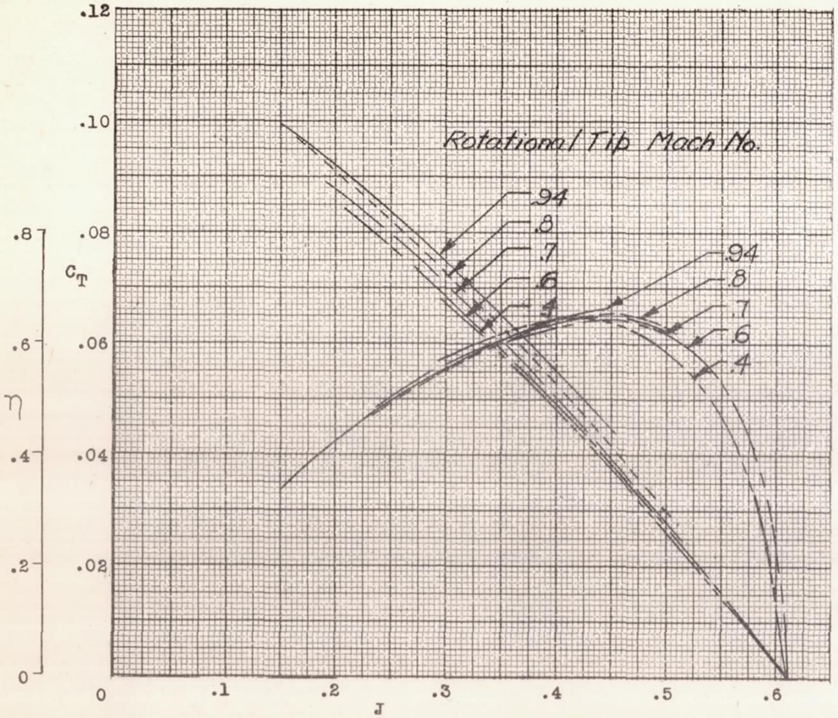


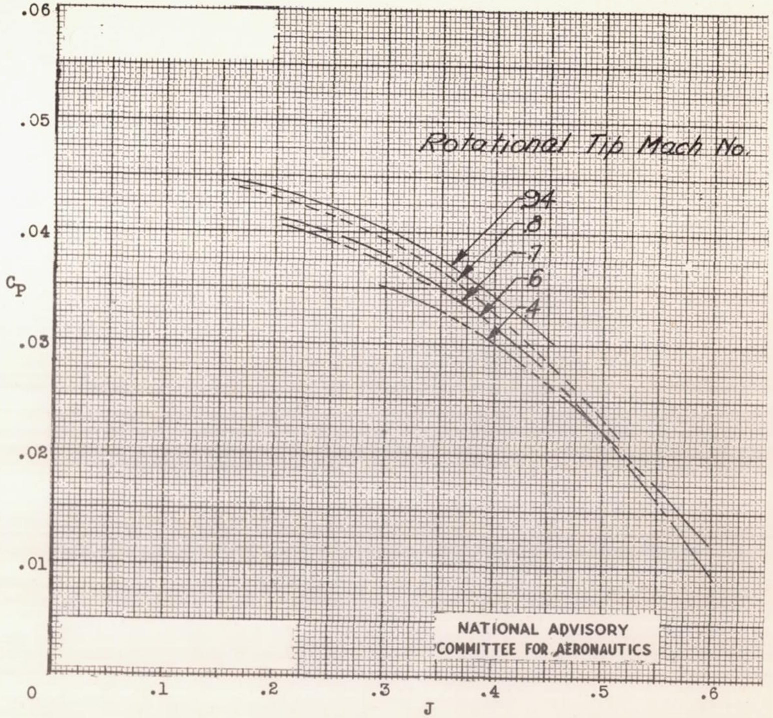
Figure 15.- Effect of flap deflection upon efficiency for C_p = .055. Landing gear extended.



(a) 16-series.

Figure 16.- Effect of tip speed upon propeller characteristics. Landing gear retracted; β, 10°; δ_f, 0°.





(b) Clark Y

Figure 16.- Concluded.

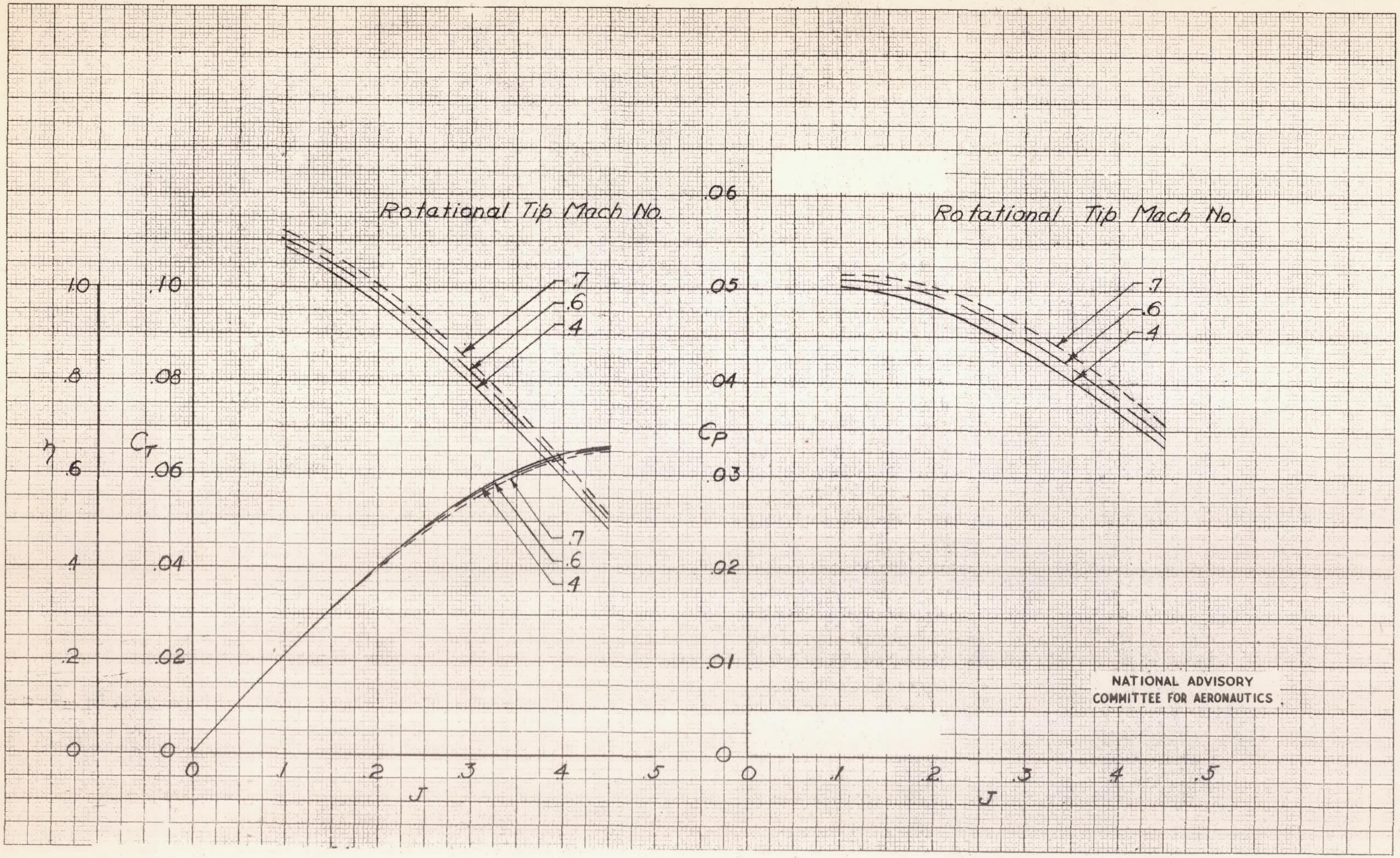


Figure 17.- Calculated propeller characteristics for 16-series propeller for 3 tip speeds. β, 10°.